MACHINERY REPAIRMAN 1 & C

NAVY TRAINING COURSES

NAVPERS 10531

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MACHINERY REPAIRMAN

1 & C

Prepared by
Bureau of Naval Personnel

NAVY TRAINING COURSES

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PREFACE

This training manual is intended to meet the needs of naval personnel who are preparing for the ratings of Machinery Repairman 1 and C. Combined with the necessary actual experience, this course should prepare them for examinations based upon the qualifications for advancement in rating outlined in appendix II of this volume.

The preceding volume, *Machinery Repairman 3 and 2*, NavPers 10530, dealt with machine shop processes and equipment. The first few chapters in this present manual are an expansion of the instruction on the use of shop machinery. The second half of this book, however, covers additional subjects: the principles of propulsion plants and of Diesel engines; the fundamentals of refrigeration, and a discussion of the Freon–12 plant; air conditioning and the principles of the Freon–12, steam jet, and lithium bromide plants; and a description of balancing machine procedures, with some discussion of the various types of balancing machine and of the methods used to restore machine parts to dynamic balance.

There is also a chapter, of particular interest to the Chief Machinery Repairman, on the proper organization and administration of a machine shop. This chapter includes rules for the care of tools and equipment, suggestions for reference material to be maintained for the use of men working in a machine shop, suggestions for the planning and assigning of work in a machine shop, and a discussion of the qualifications that a good supervisor must possess.

This book is one of the NAVY TRAINING COURSES prepared by the Navy Training Publications Center for the Bureau of Naval Personnel. Technical assistance in its preparation has been rendered by the Bureau of Ships.

READING LIST

NAVY TRAINING COURSES

Machinery Repairman 3 & 2, NavPers 10530.
Metalsmith 3 & 2, NavPers 10565–A.
(Chapters 2, 3, 4, 5, 8, 10.)
Use of Tools, NavPers 10623–A.
Blueprint Reading, NavPers 10077.
(Chapters 1–7, 11, 12, 14, 15.)
Basic Machines, NavPers 10624.

OTHER NAVY PUBLICATIONS

BuShips *Manual*, Chapters 4; 6; 31; 41, Sect. I, parts 4–10; 48; 88.

USAFI

United States Armed Forces Institute (USAFI) courses for supplementary reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Number	Title
J 362	*Arc Welding.*
J 363	*Gas Welding.*
J 367	*Introduction to Machine Industry.*
EM 912	*Blueprint Reading at Work.*
EM 965	*Machine Tool Operation I.*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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MACHINERY REPAIRMAN

1 & C

CHAPTER 1

A BIGGER JOB

INTRODUCTION

Always eager to improve his status, man early developed machines to make the accomplishment of his work easier. Before recorded history he had developed the wheel and axle, the lever, the inclined plane, the wedge, the pulley, and the screw—the six "simple machines," as we know them today.

Gradually, in recorded time, man has combined these six simple machines into ever more complex machines until today we have propulsion turbines of 45,000 horsepower, electric generators with capacities of over 4,600 kilowatts, and gasoline and Diesel engines of more than 2,000 horsepower.

When, in 1947, the Navy developed its present rating structure, it recognized that even the operation and repair of present-day naval machinery constituted too large an area for one man to learn well. Operation and repair were then divided, respectively, between the Machinist's Mate and a new rating of Machinery Repairman. You are now preparing to attain first class or chief in this latter, highly specialized rating.

Just exactly what will be expected of you in your new job? The easiest way to answer this question is to suggest that you look at the qualifications for advancement in rating to MR1 and MRC; these are listed in appendix II of this book. These qualifications give you a pretty good idea of the duties you will have to perform. Compare these duties with those

of an MR3 and of an MR2 and you see that you will have to learn a great many new things to qualify for your new job. You will, of course, have to improve your military knowledge and your technical knowledge of the jobs of your rating; but in addition, and probably most important of all, you will have to learn how to assume more responsibilities as a leader. You will, as a leader, plan and organize work for your men. You will reward and discipline them. You will teach them. And you will look out for their personal interests. The quantity and quality of the work your men turn out will be determined largely by your ability as a leader. So you'll have to learn to be a GOOD leader—one whose men do THEIR work to the best of THEIR abilities.

In this chapter you are given a few pointers on how to lead men—how to supervise them and how to train them. You are also given some information about the Navy in general—Navy organization and the rating structure—that a First Class or Chief PO should know.

LEADERSHIP

How can you learn to use authority and to handle men? It's not an easy job and it can't be learned in a day, a week, or a month. But you can DEVELOP skill in handling men, if you diligently work at it every day. Below are a few fundamental principles which have been found successful in handling men. Study these principles carefully; think about them; apply them, in your thinking, to situations that have occurred or are likely to occur. Then, in your day-to-day contacts with your men, try to apply the principles to the actual situations which you encounter.

KNOW YOUR MEN.—Find out as much as you can about each of the men assigned to you. Each man is an individual and must be treated as such.

KEEP YOUR WORD.—Men will respect you for doing what you say you will do.

KNOW YOUR OWN JOB THOROUGHLY.—Know WHAT your responsibilities are and just how far your authority extends.

Know how to perform the technical skills your rating calls for. Whenever you assign a man a job or tell him how to perform an operation, you should be able to do the work better than he can. You won't be able to bluff your way for long!

Know How to Give Orders.—A good order makes clear (1) what is to be done, (2) when it is to be done, (3) how it is to be accomplished (if instructions are necessary), and (4) why it must be done (when it is practical to give this information).

Reprimand in Private; Praise in Public.—Never bawl a man out in front of his shipmates—the purpose of a reprimand is to teach, not to embarrass. Always be sure your reprimands are constructive criticism. Praise, on the other hand, should be given publicly, when practical. And it's just as important that the praise be based on fact as it is that the reprimand be so based.

Keep Your Men Informed.—Whenever possible, let your men know the purpose of their jobs. If they feel that what they are doing is important they will do better work. Always answer your men's questions honestly; if you do not have the answer, find it.

Consider the Safety of Your Men at All Times.—"Taking a chance" in order to save 2 minutes may cause everyone on the job to stop working while the doctor is trying to save one man's life. Don't permit your men to take chances. Throughout the naval service you will find safety precautions pertaining to daily routine. Always observe these safety precautions and see that your men observe them.

Take An Interest in the Personal Problems of Your Men.—Let your men know by your actions that you are looking out for their interests at all times.

The *General Training Course for Petty Officers*, NavPers 10055, and *Human Behavior and Leadership*, NavPers 10058, will give you much more information on leadership. If you have not already become acquainted with these *Manuals*, do so at once; you will find them invaluable in helping you to become a good leader. You will also want to read the

monthly *U. S. Navy Training Bulletin*, NavPers 14976, which deals extensively with methods of supervising naval personnel.

Supervision

There are many skilled workmen who are thoroughly familiar with every phase of their specialty and yet cannot supervise the work of others. Supervision is a job in itself and you must learn how to do it.

When you're in charge of a detail, you'll supervise lower-rated PO's and strikers. It will be necessary for you to assign work to these men and to see that the work is done properly and on time. Of course, it is not necessary, or desirable, to be "breathing down a man's collar" while he is trying to do a job, but you must be ON HAND to see that things go right and to give advice when it is needed.

Good supervision may be summed up in the following steps:

1. PLAN the job thoroughly so that you know exactly WHAT is to be done and, as far as possible, HOW you are going to meet the problems which are likely to arise.
2. EXPLAIN the assignment so clearly that the man who is going to do the job understands what is to be done.
3. SUGGEST methods for doing the job, but allow the man to select any method which will result in the job being well done.
4. CHECK the progress of the work, particularly in the early stages, to catch mistakes before they result in excessive loss of time, labor, and material.
5. ENCOURAGE quality in all work.
6. INSPECT each job, making sure to point out methods and reasons for eliminating unsatisfactory finished products. Be sure to recognize and give credit for outstanding work.
7. INSIST on the use of manufacturers' instruction books and applicable blueprints.

One of your primary duties as MR1 or MRC will be to instruct your men in the performance of both their technical jobs and their military duties. The fundamental principles of leadership, of course, apply to the teaching-learning situation as much as to any other situation in which you are dealing with men. But there are a few SPECIFIC principles, dealing with efficient learning and how to help it happen, that you should know about.

Maybe you consider yourself already a fairly good instructor. After all, you know the operating principles of all machine shop equipment, and it should be a simple matter to explain them to someone else. However, this is not necessarily so. You must not only be thoroughly familiar with the subject, but you must also know how to impart your knowledge to others. Instructing is a complicated skill, and you will have to train yourself to be an effective teacher. The following suggestions will help you if you conscientiously apply them.

KNOW YOUR SUBJECT.—It is not enough to have merely read about the subject in a book. To be able to explain it to someone else, you must thoroughly understand it.

PLAN THE LESSON.—First of all you must decide exactly WHAT you want to teach—what knowledge or skill you wish your students to learn. Then you must plan HOW you are going to teach the knowledge or skill—what information you are going to give them, what questions you are going to ask, and what training aid you can use.

MAKE THE TASKS MEANINGFUL.—This can be done in two ways: (1) by tying new material in with what the student already knows, and (2) by showing the student how the new material relates to his particular duties.

REGULATE THE SIZE OF THE TASK.—It has been found that WHOLE LEARNING is often more efficient than PART LEARNING, when the material to be learned forms a logical and meaningful whole unit. However, no one can be expected to learn a lengthy and complicated task all at once. Your problem

as an instructor is to learn how to break down a complicated task into component parts which are meaningful units of work. If a job falls into four logical parts, breaking it down into five or six parts will only increase the difficulty of learning.

Have Your Men Participate.—Watching someone cut a spur gear on the milling machine will help a little, but we do not really learn until we actually perform the operation. See that your students spend as much time as possible in active doing and as little as possible in listening or looking.

Use More Than Words.—In on-the-job training you will, of course, have the actual equipment on which to demonstrate. In the classroom, you should use charts, diagrams, working models, sound movies, and slides to supplement oral descriptions.

Repeat and Drill.—Complex acts and skills are not learned without repetition. Drill, however, should be used wisely. It should be spaced to avoid monotony and fatigue. Several short periods of drill, spaced over a period of time, are better than one long period.

Let the Student Know How He Is Progressing.—The student must have a clear picture of what he is aiming at in the way of knowledge or performance, and then he must know how well he is getting along toward the goal.

Use Much Reward, Little Punishment.—Correct responses should be amply rewarded; incorrect responses are better rectified by calling attention to the right response than by punishment. In a few situations and for a few people, of course, punishment is necessary, but, in general, praise for good work gets better results than blame for poor work. Reward for desirable performance may be in the form of praise or simply a sincere "well done."

Much of your teaching will be in the form of actual shop practice, but you will be expected also to lead discussions, deliver lectures, and give demonstrations. If it is consistent with the work to be performed, keep adding new and unfamiliar tasks to the regular duties of your men. You will then have to teach the men the proper way to perform their newly

assigned duties. Thus, the men's knowledge of their trade is broadened, and your teaching ability is improved. The Navy gains both ways.

More detailed discussions concerning teaching Navy men are included in *Manual for Navy Instructors*, NavPers 16103–B, and in the *General Training Course for Petty Officers*, NavPers 10055. Refer to the these often for information on how to perform your duties as an instructor.

BACKGROUND INFORMATION

As stated earlier in this chapter, the qualifications for your rating tell you what you MUST know to qualify for First Class or Chief. But these qualifications do not tell the whole story, for as a LEADER you will also be expected to know a great deal about the Navy. The strikers and the men in the lower rates may ask you all sorts of questions about the Navy—and you will be expected to know the answers. For example: What does CNO do? What is a task force? What is an emergency service rating?

Do you know the answers to these questions? Probably not; so right now is a good time to brush up your knowledge of such things. The information given here should help you answer many of the questions which your men will ask about the Navy.

Organization for National Security

Have you ever wondered what makes it possible for the Navy's men and ships and planes to function as a team in carrying out the mission of protecting our national security? How, in wartime, the Navy is able to supply ships and planes and small craft that range far and wide to strike heavy blows against the enemy? How it can deliver clothing, food, and hundreds of other necessities to men at advance bases throughout the world? Or how it can turn "landlubbers," taken from the factories and farms of America, into salty sailors within a relatively short time?

Here is the answer: the guiding force behind all these

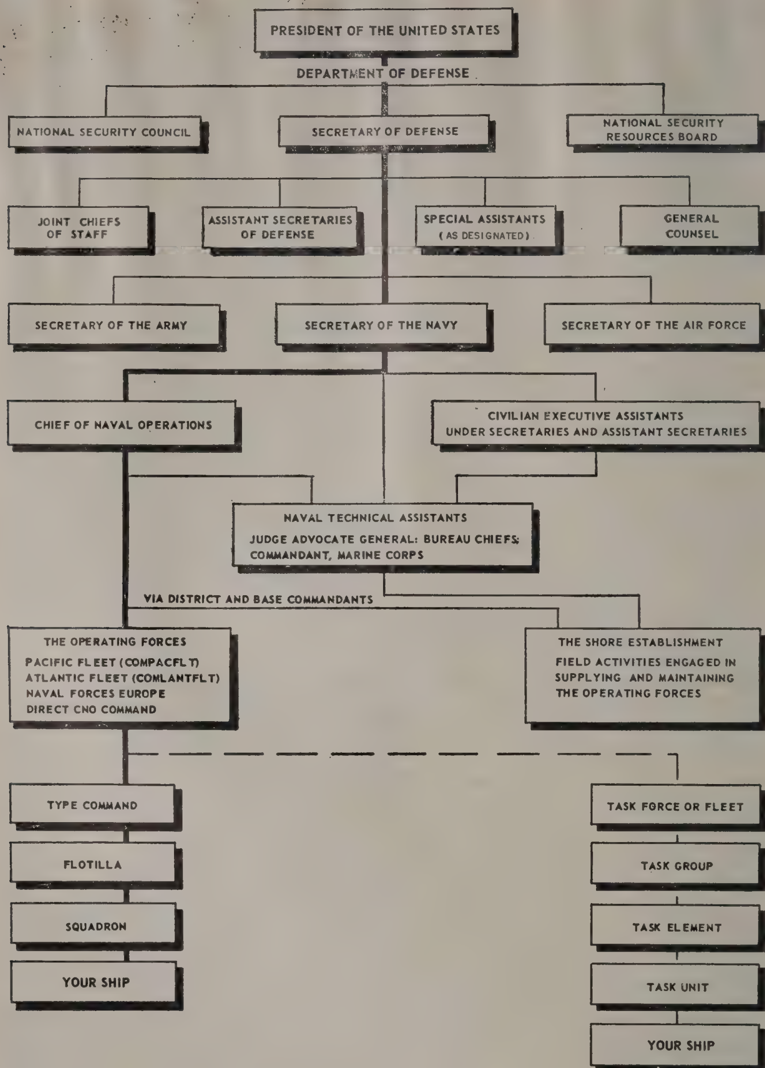


Figure 1–1.—Your ship in the organization for national security.

achievements is ORGANIZATION. Without organization the Navy could never do its job, for there would be no broad authority, no clear-cut responsibility, no coordinated effort; men would work at cross purposes and accomplish little. It

is organization that provides the framework through which plans are formulated, authority and responsibility delegated, quality and quantity of work controlled, materials procured, and objectives attained.

The present organization for safeguarding our country's security was set up in 1947 by the National Security Act (amended in 1949). The passage of this Act gave formal recognition to the need for a more compact defense structure. It unified the three arms of defense—the Army, the Navy, and the Air Force—into a single agency, the Department of Defense, and also created two high-level policy boards, the National Security Council and the National Security Resources Board, to advise the President on national defense matters. (See fig. 1–1.)

From your point of view, the DEPARTMENT OF DEFENSE, embracing all of the nation's military forces, is the most important single result of the National Security Act. This department is administered by the SECRETARY OF DEFENSE (SecDefense) who, as a cabinet officer, is appointed from civilian life by the President with the advice and consent of the Senate. The individual appointed to this cabinet position cannot have served as a commissioned officer in a regular component of the Armed Forces within the 10-year period previous to his appointment. The Secretary of Defense is the President's main adviser in matters concerning national security and is at all times responsible for the adequacy of our nation's protection. In addition to being a presidential adviser, he is the Department's top administrator. As such, it is his responsibility to see that the three arms of the military force work together and that duplication in such matters as procurement, supply, transportation, and research is eliminated.

To accomplish this enormous task, the Secretary of Defense has many assistants and his staff is subdivided into many organizational units, each of which is charged with specific duties. His principal advisers are the Secretaries of the Army, the Navy, and the Air Force; and the Joint

Chiefs of Staff. The Secretaries of the three service branches are civilians appointed in the same manner as the Secretary of Defense.

The JOINT CHIEFS OF STAFF is the military advisory body to the Secretary of Defense. The staff's membership includes a Chairman; the Chief of Staff to the Commander in Chief, if there be one; the Chief of Staff, Army; the Chief of Naval Operations; and the Chief of Staff, Air Force. This top-ranking military group is responsible for strategic planning, directing the military forces, establishing unified commands where necessary, formulating joint educational and training policies for the services, and reviewing major military, material, and personnel requirements for carrying out strategic plans.

Thus far we have traced the chain of authority from the President down to the secretaries of the three services that make up the Department of Defense. This description should give you an over-all picture of the organization for national security and the coordinating functions of the Department of Defense. Now we shall describe briefly the organization of the service with which you are most concerned, the Department of the Navy, and finally we shall show how your ship fits into this organization. As you study this material, refer frequently to figure 1–1.

Department of the Navy

The Department of the Navy, although subject to the general direction, authority, and control of the Secretary of Defense, is directed and supervised by the Secretary of the Navy (SecNav). The organization through which the Secretary works is composed of three principal parts: (1) the Navy Department, (2) the Shore Establishment, and (3) the Operating Forces. The first of these is primarily concerned with executive administration; the second, with facilities for supply, construction, and repair; and the third with carrying out the Navy's mission as a military unit.

The NAVY DEPARTMENT, located at Washington, D. C., is the

executive headquarters of the Navy. It consists primarily of the Executive Office of the Secretary of the Navy (EXOS); the Office of the Chief of Naval Operations (OpNav); the Office of the Judge Advocate General; seven bureaus (BuShips, BuPers, BuAer, BuOrd, BuSandA, BuMed, and BuDocks); and the Headquarters of the Marine Corps. It is from the Navy Department that over-all policy, command, and administrative and logistic direction of both the Operating Forces and the Shore Establishment stem.

The SHORE ESTABLISHMENT is composed of such activities as naval shipyards, naval air-bases, manufacturing plants, supply depots, training centers, hospitals, and similar units which are not parts of the Operating Forces. These activities are field units of the various bureaus and offices of the Navy Department; each unit is under the technical supervision of the bureau or office primarily concerned with its work. Located throughout the United States and the outlying territories, these activities support the fleet and provide essential facilities and services.

The OPERATING FORCES are composed of the several fleets, seagoing forces, sea frontier forces, district forces, and such shore bases and activities as may be assigned to them. Upon the Operating Forces rests the broad responsibility of fulfilling the Navy's role of supporting national policies. All the facilities set up in the Shore Establishment exist for one purpose only: to support the Operating Forces.

The CHIEF OF NAVAL OPERATIONS is the top-ranking officer of the Department of the Navy. He is the Navy representative on the Joint Chiefs of Staff and the principal adviser to Congress and the President on matters pertaining to the size and composition of the Operating Forces necessary to fulfill the Navy's role in support of strategic plans. He also determines the disposition of the Operating Forces and exercises military command over the bureaus and offices of the Navy Department, the Shore Establishment, and the Operating Forces.

To some extent, each activity within this vast organization of the Department of Navy influences every step of your naval

career. However, those units outside the sphere of the Operating Forces which will have the greatest influence on you—and those you're expected to know most about—are the Bureau of Naval Personnel (BuPers) and the Bureau of Ships (BuShips).

BuPers, as you already know, is the activity which was responsible for recruiting you into the Navy. It orders both enlisted and officer personnel to duty stations. This Bureau also has major responsibility for the training of naval personnel, including the Naval Reserve. When the time comes, it will consider your request and determine your eligibility for advancement in rating. In addition, BuPers is charged with the administration of recreation and welfare activities and of discipline.

BuShips is responsible for the design, construction, procurement, and maintenance of ships and small craft. This Bureau will influence your job and that of the men who will be working for you to the extent that it determines the type of equipment provided in ships, small craft, and repair shops where Machinery Repairmen work and, through the *Bureau of Ships Manual*, issues instructions on the operation and maintenance of that equipment.

Other bureaus are concerned with your pay (BuSandA), your health (BuMed), and the guns you man at general quarters (BuOrd).

Your Ship

Except when you are on tour of shore duty at a naval station, base, or training center, you will be assigned to a ship within the organization of the Operating Forces. Whether your ship is large or small, whether she is propelled by Diesel engines or by steam, and whether she is a combatant ship or an auxiliary ship, she'll be an important part of CNO's responsibility. On some occasions your ship may operate independently under direct orders of CNO, but as a general rule her movements will be directed by type commands, whose authority stems from CNO.

For tactical or administrative command, your ship will operate in one or more of the following (see fig. 1–1):

FLEET—an organization of ships and aircraft under one commander, normally comprising all types of ships and aircraft necessary for major operations.

FORCE—a major subdivision of a fleet.

TASK FORCE—a force that has been organized to accomplish a special task.

TASK GROUP, TASK ELEMENT, TASK UNIT—subdivisions of a task force, organized to carry out specific assignments.

DIVISION—the basic unit of fleet vessels, composed of two or more vessels of the same type.

SQUADRON—two or more divisions of vessels. (Ordinarily a squadron is composed of vessels of the same type, but at times divisions of different types make up a squadron. At times, too, a squadron may be a separate organization whose commander operates directly under orders from CNO.)

FLOTILLA—two or more squadrons of submarines or destroyers.

TYPE ORGANIZATION—a subdivision of the Atlantic Fleet or Pacific Fleet into vessels of the same type. Any type organization may have a flagship, tenders, and aircraft assigned to it. The type organization is mainly an administrative organization set up to promulgate and carry out Navy Department directives.

New Rating Structure

It takes many skills and much special "know-how" to keep the Navy operating efficiently. In peacetime, each man is required to perform a great many related jobs. In wartime, however, when the naval personnel force is greatly expanded, the variety of jobs that each man performs is decreased, and the degree of specialization is correspondingly increased. The new rating structure provides for the Navy's needs under both peacetime and wartime conditions.

In order to understand the new rating set-up, you must first understand the difference between a RATING and a RATE.

By definition, "a RATING is a name given to an occupation which requires, basically, related aptitude, training, experience, knowledge, skill, and responsibilities." Thus, the rating of Machinery Repairman is reducible to the rates of Chief, First Class, and so on down to the striker for the rate of Machinery Repairman Third Class.

A GENERAL SERVICE RATING is the rating held by a man on active duty in the REGULAR NAVY during PEACETIME. These Regular Navy men are the nucleus of a force which can be expanded quickly in the event of war. During peacetime Machinery Repairmen perform duties concerned with the maintenance and repair of all types of machinery. They may be assigned billets States-side or overseas, ashore or afloat; and they may be required to perform many general, over-all duties. These Regular Navy men make up the experienced teaching personnel at Machinery Repairman schools and training centers. During a period of national emergency all men in a general service rating will be assigned to appropriate emergency service ratings.

An EMERGENCY SERVICE RATING covers an occupational area much narrower than that of the general service rating. It is designed to make use of civilian skills and occupations in the event of a NATIONAL EMERGENCY. Only Naval Reserves are enlisted directly in the emergency service ratings. Following demobilization, a man holding an emergency rating who wishes to remain on active duty in the Regular Navy is required to qualify in the general service rating embracing the emergency service rating held during the period of emergency. Men who are demobilized but belong to either the Organized or Volunteer Reserve retain their emergency service ratings. For advancement in rating members of the Organized Reserve must participate in regularly scheduled drill periods and a 2-weeks' tour of active duty each year, when facilities for the latter are available.

The Navy job classification system on which the new rating structure is based provides JOB SKILL INFORMATION about enlisted persons, in the form of JOB CODE NUMBERS. Each rated person in the Navy has a job code number. Although your

rating badge might tell everyone, at a glance, that you're a Machinery Repairman First, and the fact that your enlistment in the Regular Navy or in the Naval Reserves indicates whether you're holding a general or emergency service rating, your job code number tells much more. In addition to describing your specialty as closely as possible, it describes other skills you have besides your specialty. So know your code number and keep it up to date. For example, if you have completed a course at Machinery Repairman school or gained additional experience on particular ships or stations during a tour of active duty, be sure that this information is recorded in your service jacket. A list of Navy job code numbers and descriptions may be found in the *Manual of Enlisted Navy Job Classifications*, NavPers 15105. Information from the job classification manual will also help you in performing certain of your new duties as Machinery Repairman First and Chief Machinery Repairman; among these is, for example, evaluating a striker's experience so that you may intelligently assign him work or advise him on additional training he may need.

LOOK AHEAD

There's practically no limit to how far you can advance in the Navy. Your advancement will depend on your ability and on hard work. Of course, an appropriate billet will have to be available but if you have what it takes you will get the billet when it is open.

When you make First Class, you should be looking ahead to the time when you can qualify for Chief. You must work hard to master the skills of your trade and to gain experience in assuming responsibility. By "taking over" on occasions for the Chief, you can prepare yourself for the duties he normally performs. In fact, there is no sharp line of demarcation between the duties of the First Class and those of the Chief. The Machinery Repairman First Class who willingly accepts added responsibilities and can perform the duties expected of the Chief is the most likely candidate for

advancement; the same holds true for the Chief seeking advancement to Warrant.

A candidate for advancement to Chief Machinery Repairman can look ahead to such jobs as taking musters, keeping discipline among his men, and preparing records and reports. His assignment makes him the "boss" and he is responsible for maintaining schedules and organizing repair work and procedures. In other words, the efficiency and successful operation of the repair unit to which the Chief Machinery Repairman is attached depends on him.

The senior Chief Machinery Repairman at times will serve as assistant to engineer or repair officers, a job usually assigned to a WARRANT MACHINIST. In this capacity, he will have charge of all maintenance work. He will, in turn, assign other chiefs and first class men to shops set up for specialized maintenance and repair. He will maintain contact with other departments to insure that spare parts, tools, and necessary repair materials are available. He will accept the full responsibility for assigned work, realizing that this responsibility is given him only because his officers have full confidence in his ability. To qualify for Warrant Machinist 7441 (Machinist), you'll have to learn the duties required of men in the other engineering ratings, in addition to the knowledges and skills required of Machinery Repairman.

A successful career in the Navy requires a lot of book work. And, as you have found out up to this point, it takes practice and hard work to acquire skill in repairing machinery. However, by combining study and work, and by keeping your conduct at 4.0 level, your chances for success are excellent. Remember, it pays dividends to know a little MORE than is required, whether it's Navy organization, principles of training and supervision, or the procedures for repairing machinery.

QUIZ

1. Where will you find a list of the duties generally performed by a Machinery Repairman First Class and a Chief Machinery Repairman?
2. What four factors should a good order include?
3. In supervising work, why should you check the progress of the work in the early stages?
4. What should you use in addition to words in teaching your men?
5. What are the three principal parts of the Department of the Navy?
6. What officer is the Navy representative on the Joint Chiefs of Staff?
7. What activity in the Navy Department is responsible for assigning you to your duty station?
8. What activity issues instructions for the operation and maintenance of the equipment with which you are concerned?
9. What is a task force?
10. What is a rating?
11. What naval personnel hold emergency service ratings in peacetime?
12. What does your job code number tell you?

CHAPTER 2

ORGANIZATION AND REPAIR PROCEDURES

Since most Machinery Repairman assignments are made to repair ships or tenders, it is important for you to have a general understanding of their organization and of the administrative procedure by which fleet repair is accomplished.

This chapter describes the various types of repair ships and tenders to which you might be assigned, the organization of their repair departments, their procedures for handling repairs, the requisitioning of materials and supplies, and the fiscal procedures involved in repair work.

COMPARISON OF REPAIR SHIPS AND TENDERS

Although the development of repair ships and tenders has reached a certain degree of specialization, all of the ships have many common characteristics and facilities which make them suitable for general work as well as the specific task for which they were designed. Shop facilities and items of repair equipment are similar; the main differences are in size and emphasis, and in the fact that some ships have special equipment suited only to a particular type of work.

The basic difference between repair ships and tenders is one of function. Repair ships are primarily concerned with maintenance, in support of various types of vessels or craft; tenders, on the other hand, support in all respects the specific types of ships to which they are assigned. Thus, on a repair

ship there are general maintenance facilities for a number of types of craft, and stocks of commonly used repair parts. On a tender the facilities are specific to the type of ship tended, and the material items are peculiar not only to that type but to the particular class composing the squadron to which the ship is attached. In addition, the squadron depends on the tender for ammunition, general stores, medical facilities, services, and often quarters, as well as for repair services.

DESCRIPTION OF REPAIR SHIPS

Repair ships fall into the following classes:

1. AR—Repair Ship.
2. ARB—Battle Damage Repair Ship.
3. ARG—Internal Combustion Engine Repair Ship.
4. ARH—Heavy Hull Repair Ship.
5. ARL—Landing Craft Repair Ship.
6. ARS—Salvage Vessel.
7. ARS(D)—Salvage Lifting Vessel.
8. ARS(T)—Salvage Craft Tender.

AR

The AR is designed to meet the maintenance requirements for capital ships, such as battleships, cruisers, or carriers exclusive of aircraft. It has the largest and most complete shops found on any repair ship or tender; they are capable of handling hull, machinery, electrical, and ordnance work. The repair materials carried in stock include general utility hull and machinery items, gyro parts, navigational equipment, typewriter repair parts, internal communications equipment, electronics items, and motion picture equipment. Some of the ships were constructed for their present function; others were merchant marine hulls converted to naval use. Displacements vary from about 11,000 to 16,000 tons. These ships can accommodate from 35 to 65 officers and 700 to 1,000 men. Most AR repair ships have two booms with a lifting capacity of 20 or 30 tons. The engineering plants

develop from 2,500 to 11,000 shaft horsepower, and generating capacity in both a-c and d-c is from 1600 to 4500 kilowatts.

ARB

The ARB, or battle damage repair ship, was a wartime development—a converted LST. It performed battle damage repairs, primarily above the waterline, of such extensive nature as to restore the damaged ship to operation. The equipment on this type of repair ship emphasizes structural repair facilities. These ships are of about 4,100 tons maximum displacement and can accommodate about 20 officers and 250 men. A 50-ton lifting capacity is provided with a stiff leg crane. The shaft horsepower developed in the ship is 1,800 and the generating capacity is 600 kilowatts. ARB's do not operate as repair units in peacetime, and they are, therefore, presently laid up in the Reserve Fleets.

ARG

The ARG, an internal combustion engine repair ship, has as its primary function the repair of Diesel engines. Its largest and best-equipped shops are those dealing with the special functions of engine repair, such as injector repair and testing. A 6-months' stock of repair parts is carried for every type of Diesel engine found in the forces afloat. The ARG's were converted from Maritime Commission (Liberty) hulls of about 14,000 tons displacement with accommodations for about 30 officers and 500 men. Boom capacity of 22 tons is provided. The ships have a shaft horsepower of 2,500 and generating capacity of 1200 kilowatts.

ARH

There is only one heavy hull repair ship in the United States Navy, the USS *Jason*, ARH–1. She has much the same characteristics as the AR class of repair ship, but is modified to provide for the accomplishment of structural repairs of a heavy nature, in addition to having many of the

usual repair facilities. Thus, her shipfitting, welding, burning and cutting, blacksmith, and similar equipment is of greater capacity than other repair ships, while the optical, radio, instrument, fire control, sound, and gyro repair facilities are somewhat curtailed. The ship is also capable of regunning batteries as large as 5 in. and 6 in. and of accomplishing heavy machinery and ordnance jobs other than gun repairs. She is fitted with two independent salvage pumps with outboard connections and ample suction hose. The ship's displacement is 16,200 tons, and she has accommodations for 68 officers and 1,090 men. Two booms of 20-ton capacity are installed. The shaft horsepower is 11,000, and the generating capacity is 750 kilowatts.

ARL

The ARL, landing craft repair ship, like the ARB, was a wartime development, converted from an LST. The purpose of this type is to provide the normal maintenance requirements for 12 LST's, 12 LSM's, 12 LCI(L)'s, 12 LCT(6)'s and some others, such as LCS's and small craft. It differs from the ARG in that, although it has facilities for Diesel engine repair, the repair parts and equipment it carries are limited to those necessary for the engines found on the above-named craft. The equipment is designed to provide for the necessary hull and electrical work and repair materials peculiar to the landing craft types. The ship characteristics are the same as the ARB's.

ARS, ARS(D), and ARS(T)

The three remaining repair ship types listed, the ARS, ARS(D), and ARS(T), are smaller units without full-fledged repair departments or facilities. They are designed for advanced salvage operations and are fitted with diving and salvage gear. They can perform certain underwater repairs of a temporary nature necessary to ensure the safety of a vessel during her return to the nearest repair activity.

The ARS was converted from a tug hull, and has a dis-

placement of about 1,800 tons and accommodations for 7 officers and 113 men.

The ARS(D) displaces about 1,080 tons and has accommodations for 8 officers and 57 men. It has a boom capacity of 10 tons, but for direct lifts over the bow or the side its capacity is 30 and 60 tons, respectively.

The ARS(T) is a converted LTS used for tending salvage craft.

DESCRIPTION OF TENDERS

Tenders fall into the following classes:

1. AD—Destroyer Tender.
2. AS—Submarine Tender.
3. AGP—Motor Torpedo Boat Tender.

AD

The AD, destroyer tender, is designed to meet the normal supporting requirements of 18 destroyers. The repair plant of this type of ship is designed to provide the equipment and capacity for the afloat repairs of the destroyers tended, of which the maximum number alongside at any one time is six. Some of these ships were originally designed as tenders, while others are conversions from merchant marine types. The displacements vary from 16,000 tons to 18,000 tons, and accommodations are provided for 50 to 70 officers and 750 to 1,200 men.

In addition to the repair plant, training and hospital facilities are furnished. Training facilities include submarine attack teacher, CIC training, and similar equipment. Hospital and dental facilities are sufficient to accommodate about 2 percent of the combined crews of the destroyers tended.

The engineering plant develops from 8,500 to 12,000 shaft horsepower and the generating capacity (from 2100 to 3500 kilowatts) is sufficient for the tender and ships alongside. Other services, such as compressed air and fresh water, are also provided on the same premise. These ships, as well as all other black-oil-burning repair ship types, are fitted for

fueling at sea. An AD carries about 1,500 tons of oil usable for servicing other ships.

Materials carried include general and ship's stores, ammunition, torpedoes, and a 6-months' supply of repair items for the vessels tended. Main boom capacity is 20 or 30 tons; lifting services consist of two 4-ton cranes and torpedo-handling booms. Boating service for the ships tended is included by supplying more than the usual number of small boats to the tenders.

AS

The submarine tender, AS, is similar to the destroyer tender in characteristics and in services rendered. An AS is designed to meet the normal supporting requirements of a squadron of 12 submarines. The repair department includes special facilities for periscope, torpedo, and mine repair. In normal service, from 2 to 4 boats are held alongside for maintenance; but provision is made for nesting all 12 during nonoperational periods. AS's vary in displacement from 14,000 to 18,000 tons, and have accommodations for 50 to 100 officers and 400 to 1,500 men. (These accommodations include quarters and berthing for officers and men of at least one submarine in addition to the AS's own complement.)

The engineering plant develops 8,500 to 11,500 shaft horsepower and the generating capacity is 1200 to 2000 kilowatts. In addition, the services of water, air, and fuel are included in the facilities of the tenders; steam-driven submarine tenders carry about 20,000 barrels of Diesel oil for issue. Hospital facilities for 2 percent of the crews tended are provided aboard the AS. Attack teachers and other training facilities are installed for the use of the ships tended. Ammunition and torpedoes are stocked to a total of a complete resupply for six submarines. Stocks of repair parts and general and ship's stores are carried in amounts sufficient to supply the submarines tended for approximately 6 months.

AGP

The AGP, motor torpedo boat tender, is designed to provide the supporting requirements for 24 PT boats (2 squadrons)

All AGP's are now in reserve status. As with other tenders, the particular repair items and stores carried by these boats were for issue to the boats tended. The repair department facilities were designed for the upkeep of the wooden hulls, gasoline engines, and the torpedoes and ordnance peculiar to PT boats. The AGP's are a varied lot, converted most often from LST's, AVP's, and PG's. Displacements run from 2,800 to 10,600 tons and accommodations from 20 to 42 officers and from 240 to 320 men. Other characteristics are: shaft horsepower of from 1,800 to 6,500; a generating capacity of from 300 to 900 kilowatts; and a boom lifting capacity of 10 to 60 tons.

ORGANIZATION OF REPAIR SHIPS AND TENDERS

The organization of a repair ship or tender follows the standard ship organization which you have studied before. Since you will be assigned to the repair department, only this department will be discussed here. The chart in figure 2–1 shows the organization of the repair department.

Repair Officer

The primary responsibility of the repair officer is the maintenance of a well-organized and efficiently operated repair department. To accomplish this, he issues and enforces repair department orders which govern procedure not otherwise clearly outlined. He must also know the current work load of his department, and the capacity of his crew and of his facilities; and he must keep the service division or staff maintenance representative informed of the current status of work in order that the latter officer may properly schedule and assign ships.

It is his responsibility to review work requests received from the ships assigned for repair, and to accept or reject the individual jobs according to the capacity of his department. He is not responsible for accepting any work requests which develop after the availability of the ship has started.

In order to maintain proper standards, the repair officer must have a first-hand knowledge of conditions in his depart-

272598°—54——3

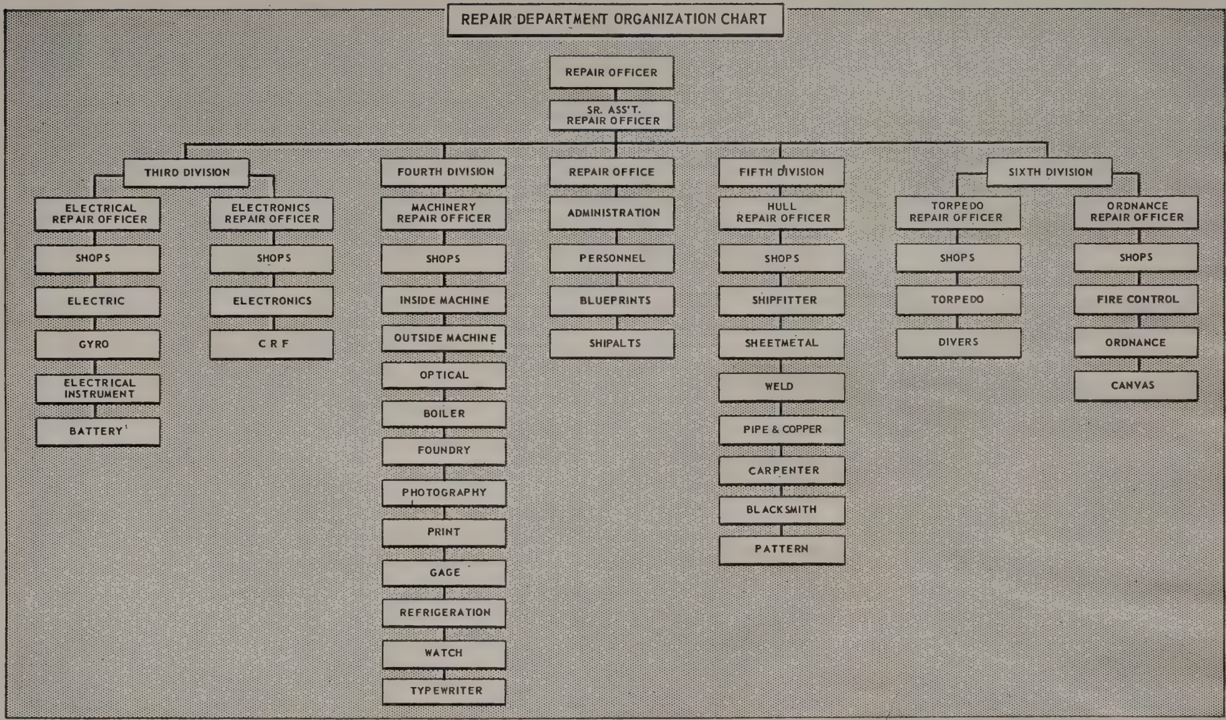


Figure 2-1.—Typical repair department organization chart.

ment; he must, therefore, make frequent inspections, and he will require his division officers to make corrections as necessary.

In peacetime when working under the allotment system, the repair officer is responsible for operating within the allotment granted, and for the initiation of requests for further funds if required.

The repair officer is also charged with the review of all personnel problems arising within his divisions in such matters as training, rating, assignment, and leave.

Assistant Repair Officer

The assistant repair officer is charged with the responsibilities of the repair officer in the latter's absence; he otherwise discharges such responsibilities as may be delegated to him. He is usually charged with the internal administration of the repair department, and the handling of department correspondence and dispatches, the maintenance of adequate files and records, and the preparation of reports. The assistant repair officer is responsible for the details of the training program for personnel in the repair department. The routing of job orders is also his responsibility, as is the dissemination of any information, such as department orders, necessary to the welfare of the personnel.

In addition to general office administration, the assistant repair officer is often assigned the more specific jobs of keeping progress data on all outstanding work, supervising the photographic laboratory, supervising the drafting room, and preparing requisition data for special material. In performing this latter function he works closely with the supply department in order to expedite the preparation of requisitions and to initiate follow-up on outstanding requisitions.

Other Assistants

In addition to the assistant repair officer, the repair officer also has the following assistants:

An ELECTRICAL assistant, who is responsible for the proper

functioning of the electrical repair, electrical instrument, gyrocompass, and battery shops.

An ELECTRONICS assistant, who is responsible for all repair and alteration work accomplished by the electronics division.

An ENGINEERING or MACHINERY assistant, who is responsible for the proper functioning of the upper (light), lower (heavy), and outside machine shops.

A CONSTRUCTION or HULL assistant, who is responsible for the proper functioning of the pattern, carpenter, shipfitter, blacksmith, sheetmetal, pipe and copper, and welding shops.

An ORDNANCE assistant, who is responsible for the proper functioning of the ordnance repair, fire control, canvas, and torpedo shops.

Diving and Salvage Officer

The duties of the diving and salvage officer may constitute a separate assignment, or may be assigned as an additional duty to one of the division officers of the repair department. In either case, the principal responsibility is the personal supervision of all diving operations. This officer is responsible for the maintenance and inspection of diving equipment, to ensure that it is always ready for use and in perfect condition. He must also enforce compliance with the diving instructions and precautions given in the *U. S. Navy Diving Manual*, 1943, published by BuShips.

The diving and salvage officer is also responsible for the adequacy and readiness of salvage gear, which includes the rigging equipment, line, cable and chain, and underwater tools such as burning, cutting, and welding outfits.

Repair Department Day Duty Officer

Unless otherwise directed by the repair officer or by the ship's organization book, the repair department day duty officer has the duties and responsibilities which are listed below:

1. In the absence of the repair officer or assistant repair officer, or when they cannot be located immediately, the day duty officer will:

a. See that incoming ships are met by a boarding officer.
b. Approve, execute, and expedite emergency and routine repair work.

2. At all times his responsibilities will include the following:

a. When his ship is at anchor or moored, he will make the *2000 security reports* to the duty commander, assuring himself, by means of any necessary inspections and by the evening reports from CPO's having the day's division repair duty, that the report is in order. (When special night jobs are going on, these reports must include information regarding the number of men working, boats away from the ship on repair work, and any unusual conditions existing.)
b. When under way, he will make a report after each duty CPO has reported the status of his division to the repair officer prior to 1900.
c. He will arrange with other departments for any assistance he may need in the repair department.
d. He will do everything possible to increase the efficiency of the repair department during his day's duty.
e. He will acquaint himself with the morning orders and see that any part which pertains to the repair department is carried out.

MR1 and MRC

As an MR1 or an MRC, you will at regular intervals be the DIVISION DUTY CPO. As an MRC, you may also be designated as a SHOP SUPERVISOR or as the SHIP SUPERINTENDENT.

As DIVISION DUTY CPO, you will be responsible for doing all of the following:

1. Inspect all shops at the end of working hours, and at such other times as may be necessary. Make security reports prior to 1900 daily concerning the number of men working at night, special jobs underway outside, and any unusual conditions existing. These reports are

made to your division officer when under way, and to the repair duty officer at other times.

2. Assure yourself of the alertness of personnel working after working hours, and expedite the accomplishment of jobs being performed by them.
3. Assure yourself that any machinery in use is being operated by competent personnel; that existing orders, instructions, and safety precautions are complied with; and that there is no unnecessary use of power, equipment, or compressed air.
4. See that all unused tools and equipment are properly secured.
5. See that there are no fire or accident hazards in the shops and that all shops not in use are kept clean and shipshape.
6. Keep the repair duty officer and men working on jobs notified of your whereabouts in order that you may be readily located.
7. When directed by the repair officers, and in cooperation with the shop supervisors concerned, take charge of any repair department work for your division which may arise outside of working hours.

If you are designated as SHOP SUPERVISOR, your duties will be as follows:

1. With the approval of your division officer, plan, schedule, and check the progress of the shop load.
2. Expedite work and inspect all jobs.
3. Ensure that the work is done in a satisfactory manner.
4. Maintain order and discipline in the shop.
5. See that the shop is kept clean and shipshape and free of fire and accident hazards.
6. Sign custody receipts for all title "B" tools and equipment issued to the shop; keep necessary records; and make inventories as directed by your division officer.
7. Approve or disapprove special requests submitted by shop personnel, explaining your reason for disapproval to the division officer at the time requests are turned over to him.

In this position you will have great responsibility, since the success or failure of the shop is to a large extent dependent upon the shop supervisor. One of your most important tasks will be to arouse the interest and enthusiasm of the men. You must constantly instruct the men in the performance of their duties, paying particular attention to those men who are new on the job. You must enforce all rules, especially those pertaining to safety and cleanliness, with wise discipline. Frequent inspections should be made to ensure that no unsatisfactory conditions, such as accident hazards, tools out of place, or unauthorized personnel in the shop, continue for any length of time. You will also supervise the use of the bulletin boards and posters in your shop. The secret of an "alive" bulletin board is the constant changing of interesting and instructive material. The *BuShips Bulletin* and *Shop Notes* contain a great deal of information which can be used for this purpose.

You should also devote sincere efforts to training a successor to replace you should you be promoted or transferred to another ship. The mission of a repair department is to render service to vessels assigned for repairs, so that they may be kept in the highest possible state of material efficiency and readiness for war. Thus your basic responsibilities as an MR1 or an MRC are to perform your work promptly, efficiently, and with high standards of craftsmanship; and to contribute in every possible way to the effective functioning of the repair department.

As SHIP SUPERINTENDENT, you will have to perform the following tasks:

1. Act as coordinator of shop work on the vessels assigned to you.
2. Act as liaison officer between the ships and the tender in regard to repair department jobs.
3. Report daily to the commanding officers of the ships assigned to you, or to their representatives, to ensure that the work is progressing satisfactorily as far as the ship is concerned.

4. Report on Friday of each week, to the repair officer, the status of each job, bringing to his attention any high priority job that is lagging. Include in this report recommendations as to the shifting of work, material procurement, and whether or not the job can be completed on time.
5. Maintain a running daily progress report or chart which will indicate (a) the percent completion of each job, (b) the availability of plans, sketches, or samples, and (c) the availability of material required for each job.
6. Maintain a follow-up check on material ordered, to ensure the timely receipt of the material.
7. Obtain signatures from officers concerned in case of cancellation of a job order.
8. Notify the ships to pick up completed material on the tender.
9. Secure signatures from officers concerned on completion of job orders.
10. Notify ships' personnel to witness tests on machinery, compartments, and tanks, occasioned by work performed.

REPAIRS AND ALTERATIONS

Maintenance work may be divided into two major groups—repairs and alterations. Repair ships and tenders may handle both types of work, although their primary work will be repairs.

Definitions

A REPAIR, as defined in *Navy Regulations*, is "work necessary to restore a ship or article to serviceable condition without change in design, materials, number, location, or relationship of the component parts." Repair work items are determined by the ship's force and approved for accomplishment by the ship's commanding officer, if the work can be accomplished by the ship's force; or by the appropriate

type commander, if the work cannot be accomplished by the ship's force.

An ALTERATION is defined as "any change in the hull, machinery, equipment, or fittings which involves a change in design, materials, number, location, or relationship of the component parts of an assembly, regardless of whether it is undertaken separately from, incidental to, or in conjunction with, repairs." Requests for alterations originate from three sources: BuShips (other bureaus may originate requests for alterations to equipment under their jurisdiction, but this discussion is limited to alterations of BuShips concern, called SHIPALT's), the forces afloat, and the Chief of Naval Operations. In any case, BuShips administers the requests for alterations. If BuShips determines that the alteration is one affecting military characteristics (a NAVALT), it forwards the request to CNO for approval and action. If the alteration does not affect military characteristics, BuShips may approve and authorize it without reference to CNO. In general, alterations of this latter type concern matters of safety, efficiency, economy of operation or upkeep, and the health and comfort of personnel.

Shipalt's

You will find that each SHIPALT is identified by a composite number consisting of two serial numbers joined by the letter "A," "K," or "D." Serial numbers are assigned chronologically in the order in which alterations are approved. The first serial number is the TYPE SERIAL NUMBER; that is, the number of the alteration within a type (BB, CL, CA, etc.). The second serial number is the SHIP SERIAL NUMBER; that is, the number of the alteration for a specific ship within the type. The letter indicates the appropriate expenditure account chargeable.

For example, consider SHIPALT CVE 621A74—Siboney. CVE is the ship type designation (in this case an escort carrier); 621 indicates that the alteration is the 621st approved for CVE's; "A" designates the account to which the

charges will be made; 74 indicates that this alteration is the 74th approved for the USS *Siboney*.

Navalt's

NAVALT's are identified by the word NAVALT and the number assigned to the applicable project in the Ship Improvement Guide, followed by the word SHIPALT and the standard identifying groups described above; for example, NAVALT 193 SHIPALT CVE 534A63—Siboney.

Alterations Equivalent to Repairs

According to *Navy Regulations*, an alteration is considered equivalent to a repair when it consists of:

1. The use of different materials which have been approved for like or similar use when such different materials are available from standard stock.
2. The replacement of worn-out or damaged parts requiring renewal by those of later and more efficient design previously approved by the bureau concerned.
3. The strengthening of parts which require repair or replacement in order to improve reliability of the parts and of the unit, provided no change in design is involved.
4. Minor modifications involving no significant changes in design or functioning of equipment but considered essential to prevent recurrence of unsatisfactory conditions.

Alterations equivalent to repairs may be approved and authorized by type commanders without reference to BuShips, provided they do not involve increases in weight or vertical moment. They are financed and otherwise administered in the same manner as repairs, except that their approval is reported to the Bureau.

REPAIR PROCEDURES

The procedures for handling repair work are essentially the same on tenders and repair ships, although the method of accepting work, that is, the channels through which work

requests flow to the repair department, may vary slightly. The following discussion will apply in general to either a tender or a repair ship.

Availability

A vessel may not informally and on her own initiative come alongside a repair ship or tender or enter a naval shipyard for repairs. The control and disposition of a vessel is at all times a function of certain operating commands. Thus, when a vessel needs outside repair assistance, the vessel's type commander—and in certain cases the task force commander—assigns the vessel an "availability" at a repair activity.

The term AVAILABILITY indicates that the ship is available to a repair activity for repair, overhaul, and/or alteration. *Navy Regulations* defines the term this way: "The period of time assigned a ship by competent authority for the uninterrupted accomplishment of work at a repair activity."

The different conditions and purposes of availability are as follows:

A REGULAR OVERHAUL is an availability for the accomplishment of general repairs and alterations at a naval shipyard or other shore-based repair activity. Regular overhauls of ships are cyclic and the period between overhauls for each type (generally 18 months) is recommended by BuShips. With the periods for the type established, each type commander prepares a regular overhaul schedule for each vessel under his command, by projecting from the date of completion of the last regular overhaul. The type commander then requires his ships to submit their respective work requests, transfers funds to the appropriate shipyards, and directs the ships to report at the assigned date to the shipyards. This type of availability concerns you only inasmuch as your ship will be scheduled for regular overhauls and you will assist in making out work requests.

A RESTRICTED AVAILABILITY is an availability for the accomplishment of specific items of work by a repair activity, with the ship present. For example, a restricted availability

would be granted for the repair of a propeller blade of a ship. Many of the ships which come alongside a repair ship or tender will have been granted this type of availability.

A TECHNICAL AVAILABILITY is an availability for the accomplishment of specific items of work by a repair activity, with the ship NOT present. This type of availability is granted when a unit of auxiliary equipment, such as a pump, needs repairing—a unit that can be detached and left for repair while the ship continues on its mission. Since the ship will not be present during the availability, arrangements must be made for the ship to deliver the defective equipment and to call for it on completion of repairs, or to provide shipping instructions.

VOYAGE REPAIRS is an availability for emergency work which is necessary to enable a ship to continue on its mission and which can be accomplished without requiring a change in the ship's operating schedule or in the general steaming notice in effect. This type of availability is very similar to restricted and technical availabilities, except that a change in operating schedule is not involved.

An UPKEEP PERIOD is a period of time assigned a ship, while moored or anchored, by competent authority for the uninterrupted accomplishment of work by the ship's force or other forces afloat. Ships are assigned upkeep periods at more or less regular intervals, usually between cruises or periods of operations.

Arrival Repair Conference

When a division or a unit comes in for an assigned availability, an arrival repair conference is usually held immediately. Representatives of the ships, of the repair department, and, usually, of the type commander are present at the conference. The relative needs of the ships and the relative urgency of each job is settled. Jobs which are stated indefinitely are specifically defined. The arrival repair conference serves to clarify all uncertainty for the repair department, which has received and studied the work requests in advance.

Services

The repair ship provides the primary services of steam and electricity in sufficient quantity to take care of heating and lighting requirements and limited power for the ships alongside. In addition to these services, the repair ship or tender usually takes over communications watches. (Fuel is not usually supplied except from service force barges.)

Work Requests

In wartime a work request was simply a list of items with the information necessary to define each job. Often, in the case of urgent work, the work request was sent out in the

WORK REQUEST
DATE:

REPAIR	BUREAU	TITLE	Group or Index No.	Ship's Serial No.
Eng.(Mech.)	Ships	----	S46	20-53

U S S DOOR CV3333	Classification -------	Priority Routine

COMAIRLANT Approval	Priority Routine	Ship's Force	Repair Ship X	Shipyard

Date Listed 4/23/53 Started Completed

Repair Ship or Shipyard (cross out one) USS SPEED AR10 J.O. No.

Brief of Repair: Include any necessary data, comment on material, and list blueprints where essential. Use back of this form if necessary.

LEAVE BLANK

IDENTIFY: Main condensate pump, Worthington Pump and Machinery Corp., Harrison, N.J. Serial No. 1120239; model A78; size 4 1/2"; speed 1145.
LOCATION: Forward engine room.
REPAIR: Remove, manufacture, and replace second-stage impeller locking sleeve. This sleeve also acts as a wearing surface for packing. It is worn to such an extent that the packing has to be renewed weekly.
SPARES: No spare sleeve provided with pump.
PLANS: Mfg. draw. No. SL-6174; BuShips plan No. CV3333-S4601-245092.
SHIP'S FORCE WILL ASSIST: Dismantle and deliver shaft assembly to machine shop; pick up and assemble pump when repairs are completed.
SHIP'S INSPECTORS: LT T.J. Ward; J.J. Johnson, MMC; M.E. March, MR1.

John Doe
Commanding

Figure 2-2.—Sample work request.

form of a dispatch. In peacetime, work requests are made on printed forms. Ships fill in the necessary data and sufficient copies of the work requests are submitted for distribution to all interested personnel. Figure 2–2 illustrates a common type of work request form used by a type command.

Work request forms are filled out by ship's personnel and sufficient copies are prepared for distribution as follows: original and one copy for the repair ship (some repair ships require two copies), one copy for return to originating ship after approval by the type command's representative, and one copy for the type command's maintenance files. The entries made on the form shown in figure 2–2 may be described briefly as follows:

BUREAU.—The title of the bureau having cognizance over the item to be repaired is filled in here.

TITLE.—This space is no longer applicable.

GROUP OR INDEX NUMBER.—Each group of machinery, structure, or equipment aboard ship bears a file number such as S16, access openings; S35, laundry; S41, main propelling machinery; and, S51, boilers.

SHIP'S SERIAL NUMBER.—Each ship numbers its work requests serially throughout a calendar year.

USS: The name of ship is entered here.

CLASSIFICATION.—Some items of equipment bear a security classification which is indicated here.

PRIORITY.—This is the priority requested by the ship—urgent, routine, or deferred.

FOR USE OF TYPE COMMANDER.—The type commander's maintenance officer, or his representative, fills in the title of the type command in this space.

PRIORITY.—This is the priority assigned to the job by the screening authority.

SHIP'S FORCE, REPAIR SHIP, SHIPYARD.—Check the activity which will accomplish the indicated repair.

DATE.—This line is self-explanatory.

J. O. NUMBER.—Job order number is filled in by the repairing activity.

Brief of Repair.—A specific statement of the work desired is necessary; it is often desirable to include the symptoms of faulty operation. It is further desirable to list the applicable drawings and to indicate whether or not they can be furnished. Where applicable, a statement is made as to which part of the work will be accomplished by the ship's force (for example, dismantling, reassembly, and delivery to and from the repair shop). Phraseology such as "do work as necessary," "check," or "open up, examine, and repair" is almost meaningless. It is frequent practice to include the name of the ship's officer who should be contacted for details if necessary and who will be responsible for inspection of the completed job.

Approved.—The dotted line is for the signature of the commanding officer of the ship.

Leave Blank.—In this space the repair activity enters such data as (1) number of man-hours on the job, (2) stub requisition numbers of material drawn, and (3) signature of person signing for the job as being completed.

As a check-off for the ship being repaired, to aid in its record-keeping after completion of the repair, some notation is made in the machinery history or other record.

Repair Department Log

With the receipt in the repair office of the work requests of a given ship, the real work of the repair department begins. Most repair departments maintain a log of incoming requests in which each request is recorded with pertinent data, such as date, ship, brief note or title of job, and a serial or job order number (assigned as the job is entered in the log). The orginal copy is then filed in the repair office in a Work Outstanding file and the extra copies are passed immediately to the appropriate shop via the division officer.

Processing a Job Order

A job order (called a work request until it has passed through the repair office) is processed about like this: The

leading petty officer of a shop calls at the repair office periodically, usually one or more times a day, to pick up the new job orders. On each job, he may indicate his estimate of the time in man-hours required to complete the work. Then he goes over each job order with the division officer, and they work out the relative priority of each job order. Sometimes it is desirable to clean up a number of small jobs before assigning a large number of the shop personnel to a single major job; on other occasions it may be more efficient to reverse that order. As work proceeds, additional conferences and continuous revision of priorities are required.

REPAIR DEPARTMENT INTERSHOP WORK REQUEST

FROM MACHINE SHOP. 5/1/53 DATE

TO FOUNDRY SHOP.

USS	J.O. NO.	PRIORITY
SPEED ARIO	609-46-53	Routine

IT IS REQUESTED THAT ASSISTANCE BE FURNISHED THIS SHOP BY ACCOMPLISHING THE FOLLOWING WORK.

BRIEF OF WORK:

IDENTIFY: Main Condensate Pump, Worthington Pump and Machinery Corp., Harrison, N.J. Serial No. 1120239; model A78; size 4 1/2"; speed 1145.

REPAIR: Cast one (1) second stage impeller.

SPARES: No spare impeller provided with pump.

PLANS: Mfg. draw. no. SL-6174; BuShips Plan No. CV3333-S4601-245092.

M. P. WORTH MRC
Officer in Charge

SHOP			
DATE STARTED:	DATE COMPLETED:	SIGNED FOR:	MAN-HOURS:

Figure 2–3.—Intershop work request.

The men are then assigned the jobs to be taken up immediately, as fast as they complete previous work. They take the job order, indicate their starting time, and begin the work.

It may be necessary to call upon another shop, or other shops, to help with a job. If, for example, an MR takes up work on the repair of a pump, he may require the casting of an impeller. He must then fill out a supplementary job order (or intershop work request) to the foundry, referencing the basic job order. (See fig. 2–3.) The shop supervisor usually signs these supplementary job orders. When the supplementary job has been completed, the supplementary job order is returned to the control shop, where it is attached to the master job order. While waiting for the casting to be done, the MR may take up other job orders.

In the process of accomplishing the work, the men must requisition supplies from the supply storerooms. (The procedure for requisitioning supplies is discussed later in this chapter.) When a job which will have been inspected at intervals by the division officer or leading petty officer has been completed, the number of man-hours on the job and the material used are indicated on the job order. The completed job order is then turned over to the shop supervisor, who returns it to the repair office for record and file.

Outside Repair Personnel

If the work to be accomplished cannot be brought aboard the tender, the outside repair personnel are organized to do repair work on the ships. They work under the general supervision of the machinery assistant repair officer. When the outside repair personnel are working on other vessels they work under the immediate supervision of their own leading petty officers, and any changes regarding the methods of performing the work to be accomplished are referred to the repair officer or the machinery assistant aboard the repair ship. These outside repair personnel are highly trained in their specialized fields. They do repair work of the same

type that the skilled yard personnel accomplish when a ship is given a naval shipyard availability.

Diving Operations

In addition to operations connected with the shops, the repair department conducts diving operations when they are required. Frequently ships have underwater trouble which is difficult if not impossible to diagnose without actual underwater inspection—one of the primary functions of diving jobs. The divers learn to inspect underwater sound gear, propellers and shafting, rudders, sea chests, and battle damage. Upon their report the decision to drydock or to attempt repair by diving is made. In wartime when ships came in with underwater damage, diving inspection was necessary prior to drydocking to determine whether there were any interferences from torn structure which would prevent successful drydocking; if there were, divers had to burn or cut away the obstruction prior to drydocking. The diver also makes a preliminary survey of the extent of damage, to assist those charged with making a decision as to the type and degree of repairs to be attempted in the forward area.

Checking Progress

Inspection of the work and the record of progress on the various jobs must be closely followed at all times by those responsible in the repair department. Normally, the division officer makes several rounds of the shops and outside activities during the day. He compromises differences of opinion between ship and repair personnel on the conduct of any particular job, expedites supplementary job orders in other divisions, and otherwise breaks any bottlenecks in the course of progress.

Progress Reports

Progress reporting varies with each repair department. It may be an informal verbal report by shop petty officers to division officers, who pass it on to the repair officer. A more formal progress report employed on one destroyer tender

JOB ORDER PROGRESS RECORD SHEET MACHINE SHOP

23 April 19 53

SHIP	J.O. NUMBER	DESCRIPTION OF JOB	DATE RECEIVED	PERCENT COMPLETE										REMARKS
				10	20	30	40	50	60	70	80	90	100	
DD807	891-48-53	Grind 6 Firemain valves	4/21/53											
DD891	893-48-53	Mfg. 3 valve stems	4/21/53											
DD891	895-45-53	Mfg. shaft for lub oil pump	4/21/53											
DD762	898-47-53	Mfg. install wearing rings for pump	4/22/53											
DD807	901-12-53	Mfg. 20 nameplates	4/22/53											
DD812	903-51-53	Grind 5 handhole plates	4/22/53											
DD812	904-47-53	Mfg. valve stem for recip. pump	4/22/53											
DD762	905-48-53	Mfg. 10 disks for flushometers	4/22/53											
DD891	906-47-53	Cut keyway in shaft	4/23/53											

J. J. Williams MRC USN

Figure 2-4.—Job order progress sheet.

involves the use of mimeographed forms (fig. 2–4) furnished to each shop. Daily, at the close of working hours, the leading petty officer lists, by number and a short description of the work, (1) each outstanding job order in his shop and (2) the percentage of the job completed. The division officer receives and notes the list and turns it in to the repair officer. Provided the officers responsible insist on conscientious reporting, this form of progress report can be of very great value to the repair officer in judging the amount of work carried, the wisdom of assignments, and the actual progress being made.

Daily Record of Man-hours

Shop supervisors also keep a daily man-hour report (fig. 2–5). This report is brought up to date at the end of each working day. In this manner, the shop supervisor has a

DAILY MAN HOUR REPORT

Shop *Machine* No. *27*

Date *5/1/53*

Number of Men *13* Total Man Hours *91*

Man Hours Expended:

Job Orders	*49*
Training	*14*
Special Detail	*21*
Sick Bay	*0*
Special Liberty	*0*
Shop Upkeep	*7*
Total Man Hours Expended	*91*

Signed *M. McKelvey MR1*

Figure 2–5.—Daily record of man-hours.

complete record of all jobs being worked on and the number of man-hours expended on each job.

Departure Report

The departure report for each ship completed is prepared by the repair ship and contains the following entries for all jobs completed for the departing ship: job order number, date, work request number, item of repair, shops assigned, date completed, and man-hours expended.

MATERIALS AND SUPPLIES

Materials and supplies are of vital importance to the successful operation of the repair department. Adequate quantities of general repair materials and repair parts for items of equipment commonly repaired are as much the responsibility of repair personnel as of the supply department. The duties of the supply officer are to procure, receive, stow, issue, and account for all types of stores involved in the support of the ship. The supply officer is not the prime user, so the initiative to keep abreast and ahead of usage must be supplied by repair department personnel. Careful use of stocks, repair experience, and advance planning are all necessary elements in avoiding costly and embarrassing delays in completing a job.

The supply officer maintains his stocks in various supply department storerooms where the material may be drawn; in addition, the various repair shops have their own small storerooms for issue of small items used piecemeal—i. e., the ship has both wholesale and retail storerooms. Material in the small storerooms of the repair department is charged for when it is originally drawn from the supply department storerooms.

Generally there are three classes of material used by the repair department: standard stock, BuShips special material, and BuShips repair parts. These classes are defined in the following paragraphs.

Standard Stock Material

Standard stock is material listed in the *Catalog of Navy Material*, general stores section. As a general rule, standard stock items are subject to complete inventory control of BuSandA. (By mutual agreement between these Bureaus, BuShips exercises certain controls over items intended for the exclusive use of BuShips where such arrangements better serve the forces afloat and BuShips; these controls, however, are of primary interest to stocking activities.) Standard stock materials are the consumable supplies carried in stock for maintenance and operating purposes; they do not include nonconsumable equipment or spare parts for this equipment.

In order to systematize the large range of materials used aboard ship, stocks are arbitrarily divided into classes. Designations have been made for 99 classes, of which the following are examples: Class 17, electrical equipment; class 33, gaskets, packing, hose and fittings, rubber and plastics; class 39, lumber; class 43, bolts, nuts, rivets, screws and washers; class 45, pipe fittings, plumbing fixtures, valves; class 47, metal in plates, sheets, and strips; class 60, steam propulsion apparatus, heat transfer equipment, and nonelectric power transmission equipment. Each item bears a stock number beginning with the class number, which may be found in the *Catalog of Navy Material* published by BuSandA.

BuShips Special Material

BuShips special material is defined as machinery or equipment under the cognizance of BuShips and, because of its design or specified use, intended primarily for shipboard use. BuShips special material is normally an item of permanent (nonconsumable) shipboard equipment (in most cases shown on ship's general arrangement drawings or Type B plans) requiring installation arrangements such as special power leads, piping connections, or foundations. Such material is not removed from storage without direct permission of BuShips, except in certain emergencies. Because of the nature of BuShips special material, it is sometimes almost impossible

to draw a sharp line between it and repair parts. In order to clarify these borderline cases the *Index of Special Material* lists such repair parts: items such as turbine blading, main propulsion reciprocating engine crankshafts, turbine rotors, etc. (Complete sets of spare parts for items of BuShips special material are classified as BuShips special material when in store.)

BuShips Repair Parts

The third class of material is BuShips repair parts. These are items such as parts, fittings, or accessories of equipment which is BuShips special material.

In order to control these parts properly, BuShips has directed certain supply offices and control centers to act as its agents in inventory control. Instructions regarding handling are promulgated by these agents. There are seven of these control centers. The one that is of most interest to an MR is the Ships Parts Control Center, Naval Supply Depot, Mechanicsburg, Pa., the control center for internal combustion engine repair parts, hull and machinery repair parts (electrical and mechanical), and special small tools.

Spare parts are essential replacement items carried by every ship; these include machinery, electronics, and ordnance spares as specified in the ships' allowance lists. These are parts frequently used by the repair ship in repair work for the ship carring them, since repair ships cannot attempt to stock the multitudinous items required.

However, tenders carry group spares for the type tended. An example of a group spare would be a large armature which can be used on any one of a class of destroyers but which could practicably be carried only on a destroyer tender. Tender stocks of "proprietary" material are called repair parts to differentiate them from the spare parts carried by an individual ship.

Means of Identifying Repair Parts

There are several sources of information available to repair personnel in identifying repair parts that may be re-

quired. First of these is the allowance list of the ship for which the part is intended; this list shows nomenclature and both Navy and manufacturer's part numbers. Name plates on equipment supply information regarding characteristics. For each item of machinery or equipment on board there is usually supplied a manufacturer's catalog and/or instruction book; these list spare parts and the manufacturer's number, and contain illustrations which are of valuable assistance in visual identification.

The ship's Machinery Index contains specific characteristics of each piece of machinery on board. If ship's plans are used for information, they should be checked against the machinery because they may fail to carry notations of changes made since the original installation. A final source of information is the supply officer's Stock Cards (NavSandA Form 484), one of which is maintained for each machinery spare part on board. These same sources of information, with the exception of the Machinery Index, serve for identification of ordnance or electronics spare parts also.

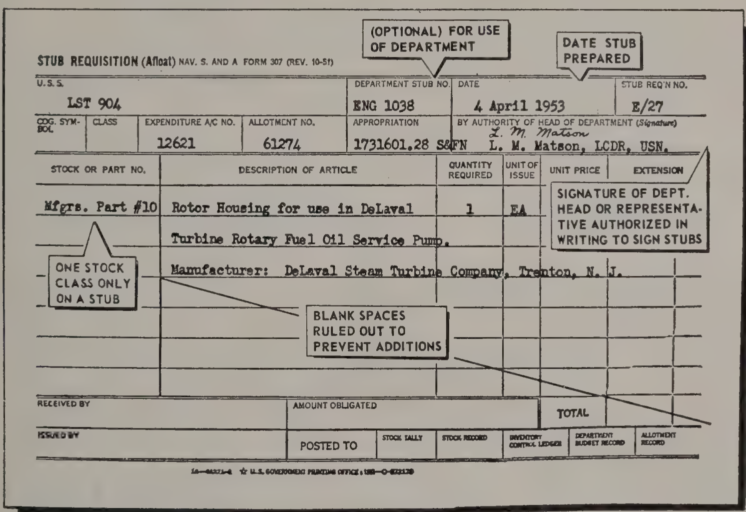


Figure 2-6.—Sample stub requisition.

Requisitioning Material

Having considered material classification and the identification of repair parts, let's now consider the process of requisitioning such parts. Figures 2–6, 2–7, and 2–8 show the principal forms used in the process.

REQUEST FOR SPARE PARTS

NAME OF ACTIVITY OR SHIP: USS LST 904	REQUEST NO.: E/27
DEPARTMENT: Engineering	DATE: 7/15/52
SPARE PART BOX NO.: S55/14	ALLOWANCE LIST GROUP NO.: S55
STOREROOM NO.: A202EA	PAGE NO.: 14

ITEM NO.	OR PART NO.	DESCRIPTION	UNIT	QUANTITY	SPARE PART LIST NO.	ALLOWANCE LIST LINE NO.
1.	10	Rotor Housing	No.	1		25

DeLAVAL TURBINE DRIVEN ROTARY FUEL OIL SERVICE PUMP

NAME PLATE DATA

SERIAL NO.: 241458	TYPE NO: Vertical, Class M-1	MODEL NO.	STYLE
MFR'S DRAWING NO.: SG-1937	NAVY DRAWING NO.: LST864-S-5501-50	P. C. NO.	CONTRACT NO: Fed. P.O. LST864-G&C-161 10/19/42
HP.: 14.4	R. P. M.: 573 (pump speed)	GPM: 50	CFM
VOLTAGE	A. C. OR D. C.	AMPS.	OHMS
PHASE	CYCLE	BORE	STROKE
SIZE	JOB ORDER NO.	CATALOG NO.: DeLaval Instructions No. 483	SPECIFICATION NO.

ADDITIONAL NAME PLATE DATA: Steam pressure 575 p.s.i. Turbine driven rotary fuel oil service pump, speed 5014

OTHER IDENTIFYING INFORMATION: Sectional diagram of pump shown in Fig. 3 of DeLaval Instructions No. 483

MANUFACTURER: DeLaval Steam Turbine Company	LATEST ACCEPTABLE DELIVERY DATE: 11/1/52

MANUFACTURER'S ADDRESS: Trenton, New Jersey

SOURCE OF SUPPLY:

DRAWN OUT OF SPARE PARTS BOX BY: C. R. Lattanner, FN	UPON RECEIPT NOTIFY: W. Morris, MM2
SUBMITTED BY: W. Morris W. Morris, MM2	APPROVED: J. D. Hobbs J. D. Hobbs, Jr., LT USN

DATE ORDERED	ORDERED FROM	REQUISITION NO.
7/18/52	NSC, Norfolk, Va.	LST904/1080/53

☆ U. S. GOVERNMENT PRINTING OFFICE : 1944

Figure 2–7.—Sample requisition for repair parts.

The 307, or stub requisition, is used for any type of material—GSM items such as lumber, screws, or bar stock, as well as repair parts. Figure 2–6 is practically self-explanatory. Each shop has its own book of stubs which are used as required for items pertaining to the repairs in hand. The division officer is the usual authorizing officer.

In the lower left corner, the signature of the repair man initiating the stub is entered opposite the "received" entry, as is the signature of the storeroom keeper when the items are issued to the repair man.

REQUISITION AND INVOICE
NAV. S. AND A. FORM 40

LST904/1080/53
REQ. NO.

INV. NO.

TO: SUPPLY OFFICER. SSD, NSC, Norfolk, Va.

U. S. S. (50904) LST 904

THE FOLLOWING ARTICLES, WHICH ARE NOT IN EXCESS, ARE REQUIRED.

DELIVER TO Supply Officer, USS LST 904

DATE 7/18/52 | BUREAU Ships

APPROPRIATION CHARGEABLE 1731601.28 S&FN Allot 61274

BY Priority C 1 November 1952

EXPENDITURE ACCOUNT 12621

PACKAGES TO BE MARKED Reqn. LST904/1080/53 RP Box S55/14

DATE OF SHIPMENT | BILL OF LADING NO.

SHIPPED VIA

REMARKS DDD assigned to meet operating schedule of this vessel

R.T. Ford
R. T. FORD, ENS U. S. N.
(SUPPLY OFFICER OR COMMANDING OFFICER, OR STORES OFFICER)

ITEM NO.	STANDARD STOCK CATALOG NO. OR CLASS NO.	DESCRIPTION OF ARTICLE	UNIT OF QUANTITY	QUANTITY REQUIRED	QUANTITY FURNISHED	UNIT PRICE	EXTENSION
	Mfgrs. Part No.						
1.	10	ROTOR HOUSING	No.	1			

For use in:
DeLaval Turbine Driven Rotary Fuel Oil Service Pump
Manufactured by:
DeLaval Steam Turbine Company
Trenton, New Jersey.

Pump Data:
Serial No. 241458 — R.P.M. 573
Mfgr Dwg No. SG-1937 — G.P.M. 50
B.H.P. 14.4 — Steam Pressure 575 psi
Type No. Vertical, Class M-1 — Turbine Speed 5014 normal
Navy Dwg No. LST864-S-5501-50 — Contract No. LST864-G&C161 Dated 10/19/42

Sectional diagram of pump shown in Fig. 3 of DeLaval Instructions No. 483.

As shown in Machinery Allowance List Part I, Group S55, Page 14 Line 25

No other requisitions for this item outstanding.

Important: Vessel shall include only items in one stock class on this form.

TOTAL

CHECKED BY | PACKED BY | POSTED AND PRICED | 1 | RECEIVED THE ABOVE MENTIONED ARTICLES DATE

RECHECKED | EXTENDED | VERIFIED

ISSUED BY | | | | BY U. S. N.

Figure 2-8.—Sample requisition and invoice.

If the item required is a repair part which is not in stock and must be procured, the identifying data may be shown on NavSandA Form 307, or on the 302 (fig. 2–7), or both. The supply officer must be furnished accurate and complete information concerning the desired part; the repair department is in the best position to furnish this information.

The supply officer prepares and sends out the requisition form (fig. 2–8). If there is insufficient advance information to allow for obtaining the desired part through routine handling of the requisition form, dispatch requisitions are resorted to. All the essential information on the requisition form is compressed into dispatch form. Dispatch requisitions were used quite frequently during the war. Even though great stocks of material were carried at advanced operating bases, it took months to segregate it.

The REQUISITION PRIORITY classifications which are in current use are:

Priority 1: Emergency; this classification is used when a vessel in the forward area is inoperative or immobile because of the lack of the part requested.

Priority 2: Overhaul; this is used for a request for repair parts for vessels undergoing or immediately scheduled for overhaul. Priorities 1 and 2 can be assigned only by the maintenance administrative command afloat.

Priority 3: Ships allowances; used to fill shortages or make replenishments of parts stocked. Priority 3 is assigned automatically if no other priority is specified.

ALLOTMENTS

The fiscal procedures under which the Navy operates are of concern to all because practically every action is limited in some manner by the budget. Details of accounting and returns are handled by the supply and disbursing officers of each ship or activity, but control over allotments and expenditures is exercised by others as well. So far as the purposes of this volume are concerned, the funds dealt with are those appropriated for the use of BuShips in the maintenance, repair, and operation of the forces afloat; these funds are designated as Maintenance BuShips, or, more commonly, MBS.

BuShips allocates that portion of its MBS funds for forces afloat to the fleet commanders and to ships, in the form of allotments. An allotment is an authorization to a

naval activity to expend a certain amount of money for ordinary maintenance repairs and operation within the fiscal year for which granted. The allotments to the ships are published by BuShips as regular quarterly allotments. Commanding officers budget these quarterly allotments between the various departments of their ships to cover the cost of normal consumable materials and miscellaneous services necessary in the maintenance and operation of the ships. Allotments granted by BuShips are the principal funds used in the material operation and maintenance of any ship; these allotments do not cover fuel, provisions, and pay.

BuShips allotments are charged with issues of both Naval Stock Account (NSA) and Appropriations Purchases Account (APA) material. When material is of a standard nature which could be used for many different purposes, it is purchased by funds from the Naval Stock Fund (NSF) and held in NSA until it is issued for use. At this time, the appropriation of the bureau which draws the material is charged for it and the Naval Stock Fund is credited with the amount of the charge; thus the Naval Stock Fund is a "revolving fund." The Appropriations Purchases Account is a storeholding account in which the Navy holds material that has already been paid for by a specific appropriation. It is the nature of the material which primarily determines whether it shall be NSA or APA. Technical material designed for a specific purpose, such as a spare part for a main feed pump, which could hardly be used for anything other than a main feed pump, is purchased by the bureau having material control, out of its own appropriation. (In this case, it would be the BuShips appropriation.)

The allotments which have been discussed are for the maintenance and operation of the ships themselves. In addition, force and type commanders grant allotments from their budgets to repair ships and tenders for work on other vessels (other than floating drydocks), as required; such allotments are recorded and handled by the repair ships and tenders separately from the allotments granted them for their own use. Repair ships and tenders receiving allotments for work

on other ships maintain separate records of such allotments and make separate allotment and expenditure reports thereon; again, this is the responsibility of the supply officer.

In order that the repair department may keep current on the status of its allotment for repair of other vessels, it is customary to obtain from the supply office a weekly statement which reflects the value of material issued to date, the unexpended balance, and the unobligated balance. With this record, the repair department can govern or budget its material requirements.

A similar report is made weekly by the supply officer to the commanding officer, indicating the status of each department in the ship's regular quarterly allotment.

QUIZ

1. What is the difference between a repair ship and a tender, with respect to the kind of support which each vessel gives to the ships assigned?
2. What is the difference between a repair ship and a tender, with respect to the nature of the ships supported by each?
3. What repair ship or tender is primarily designed for the maintenance of capital ships?
4. What repair ship or tender is used for advance salvage operations and for temporary underwater repairs?
5. What repair ship or tender meets the normal supporting requirements of 18 destroyers?
6. What is the primary purpose of the ARG?
7. What repair ship or tender is used only in wartime for extensive structural repairs above the waterline?
8. How many submarines are supported by one AS?
9. How would you define the basic responsibility for the repair officer?
10. Who is usually responsible for the internal administration of the repair department?
11. Who is responsible for the maintenance of diving equipment and salvage gear?
12. Who is, to a very large extent, immediately responsible for the success or failure of a shop?

13. If a repair job requires work from more than one shop, what person aboard the repair ship will coordinate the work of the various shops?

14. Which of the two major types of maintenance work constitutes the bulk of the work done by repair ships?

15. What kind of alterations require the approval of CNO?

16. What information is supplied by the two serial numbers and the letter following the word SHIPALT?

17. When worn-out or damaged parts are replaced by approved parts of later design, what type of maintenance work is involved?

18. What type of availability would be granted for the accomplishment of specific items of repair work which were to be done with the ship present?

19. Under what conditions is a technical availability granted?

20. Who usually attends the arrival repair conference?

21. What two primary services does the repair ship provide for the ships alongside?

22. What is a work request called after it has passed through the repair office?

23. Who keeps the daily record of man-hours?

24. What are the three classes of material used by the repair department?

25. What class of material used by the repair department is listed in the general stores section of the *Catalog of Navy Material?*

26. How would you define BuShips special material and BuShips repair parts?

27. List six sources of information for the identification of repair parts.

28. What requisition priority is assigned automatically when no other priority is specified?

29. What allotments constitute the principal funds used in the maintenance of any ship?

CHAPTER 3

TURRET LATHES AND BORING MILLS

The more complicated machine shop operations are the responsibility of the Machinery Repairman First or Chief Machinery Repairman. This chapter will prepare you for the actual doing and supervision of precision machine shop operations performed with turret lathes and boring mills. The first section introduces the horizontal turret lathe, methods of setting up, and ways of accomplishing typical jobs; the second section takes up the features, methods of tooling, and setting up of the vertical turret lathe, and examples of some of the jobs done on this lathe; and the third section describes the setting-up and uses of boring mills.

This chapter will not attempt to make a first class machinist of you—this will take years of experience; it will, however, help prepare you for more advanced machine shop duties.

HORIZONTAL TURRET LATHE

There are two classes of horizontal turret lathes: bar machines (fig. 3–1) and chucking machines (fig. 3–2). Basically the machines are alike, the difference being only in their tooling. Chucking machines are used for machining forgings, castings, and cut bar stock which must be held in a chuck or other fixture. Bar machines are used for making parts from bar stocks or for machining forgings or castings of size and shape similar to bar stock.

Bar and chucking machines may be of either the ram or

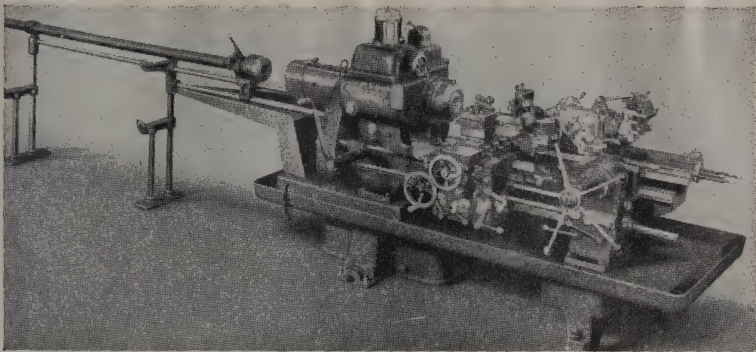


Figure 3–1.—Bar machine.

saddle type, each machine being designed to handle a certain class of work to the best advantage. Because of its rigid turret mounting, long stroke, and suitability for longer and heavier chucking work, the saddle type is most common on board Navy repair ships.

Headstock

The first important unit of any turret lathe is the headstock. Many lathes have a multiple speed motor coupled

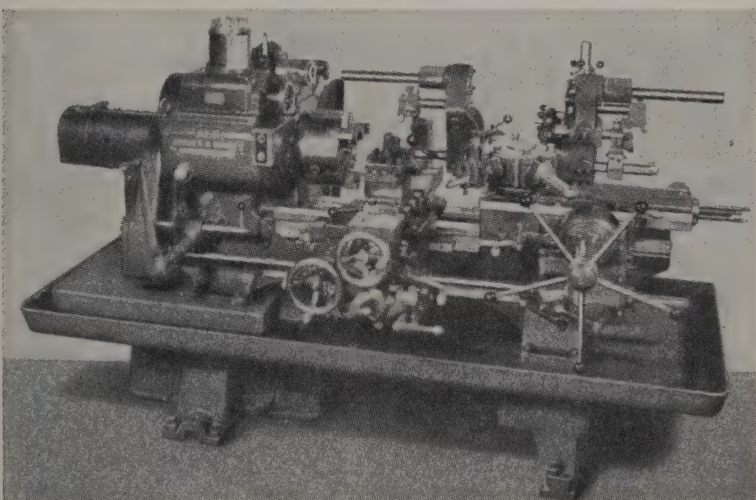


Figure 3–2.—Chucking machine.

directly to the spindle, while others have all geared heads which provide an even wider range of spindle or chuck speeds. The various speeds are obtained by moving, in proper sequence, the gear and clutch levers. A 6-speed headstock will usually have three control levers: a forward-and-reverse clutch lever; a triple gear shift lever, which is used to select any one of three groups of speeds; and a high-low clutch operating lever, used to obtain either speed of a certain group of speeds. The high-low speed changes are made directly, without using the forward-and-reverse clutch lever; but triple gear shift lever changes require the use of the forward-and-reverse clutch lever to disengage gearing before a shift is made.

A 12-speed headstock uses either a multiple lever shift or a single shift lever with a preselecting device. The multiple lever head is comprised of four levers as follows:

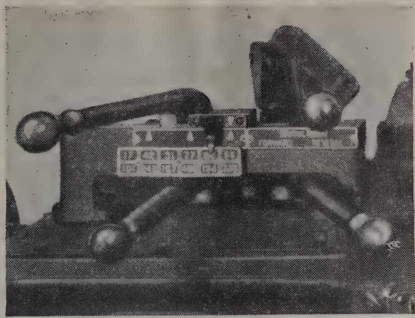
1. Triple gear shift lever.
2. Left-hand double gear shift lever.
3. Right-hand double gear shift lever.
4. Forward-and-reverse clutch lever.

In making speed changes on a 12-speed head, it is necessary to first disengage the forward-and-reverse clutch lever. Figure 3–3 illustrates diagrammatically the speed selection on the 12-speed head.

You should always engage the forward-and-reverse clutch with a steady push of the clutch lever—not with a sudden jerk. Sudden engagement forces the headstock gearing up to a full speed too rapidly and overloads the driving belts and clutch disks.

Feed Trips and Stops

To save time when making a number of duplicate parts, many horizontal turret lathes are equipped with feed trips and positive stops on the cross slide unit, obviating the measuring of each piece. For duplicating sizes cut with a longitudinal movement of the cross slide carriage, there is a 6-station stop roll in the carriage and an adjustable stop rod



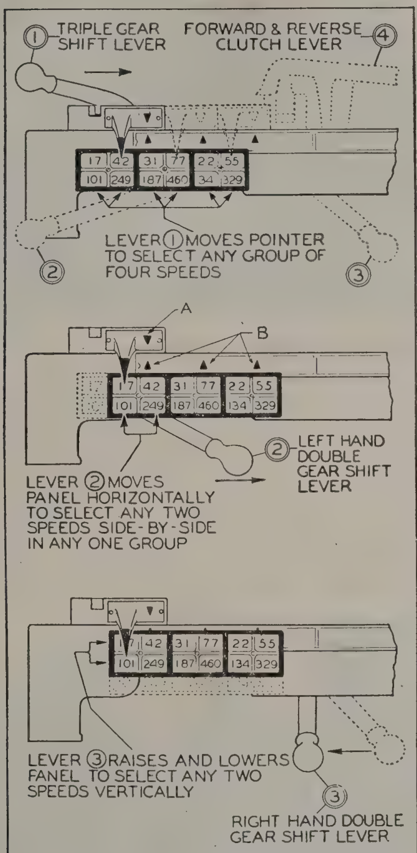


Figure 3–3.—Changing speeds on a 12-speed head.

in the head bracket. Stop screws in the stop roll provide for individual adjustment, and a master adjusting screw in the end of the stop rod provides for making set-up changes without disturbing the individual stop screws. (See fig. 3-4.)

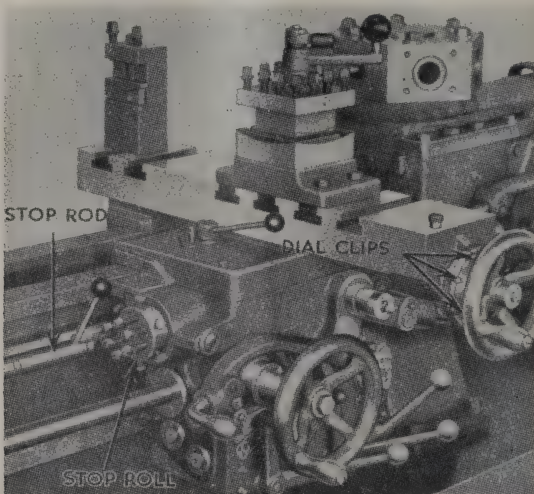


Figure 3–4.—Stop roll on a Universal cross slide.

Turret stop screws on the ram type machine are mounted in a stop roll carried in the outer end of the turret slide. The screw in the lowest position of the stop roll controls the travel of the working face of the turret. The stop screws are positioned by the automatic rotation of the stop roll with the hexagonal turret.

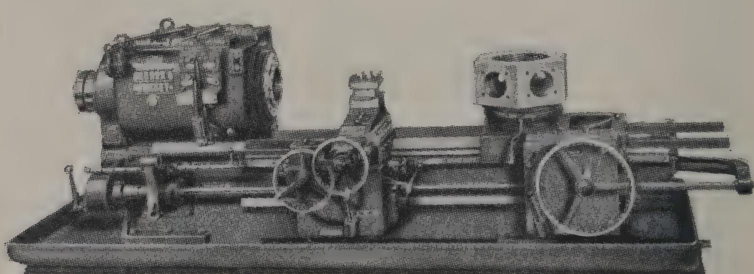


Figure 3–5.—Turret lathe feed train.

Hexagonal turret stops on ram type machines can be set as follows:

1. Run a cut from the turret to get the desired dimensions and length.
2. Stop the spindle, engage the feed lever, and clamp the turret slide.
3. Turn the stop screw in until the feed knocks off; then continue running in until it hits the dead stop.

On saddle-type machines the stop roll for the hexagonal turret is located under the saddle and between the ways. The stop roll does not move endwise, but it automatically rotates as the turret revolves. The procedure for setting the stops is as follows:

1. Move all the dogs back to the outer end of the roll, where they will be in a convenient position. Select a turret face and allow the master stop to engage the loosened stop dog. After the trial cut is taken, the stop dog will slide ahead of the master stop.
2. After you have taken the proper length of cut, stop the spindle, engage the longitudinal feed lever, and clamp the saddle. Then adjust the stop dog to the nearest locking position with the screw nearest the master stop. When the end of the dog is flush with the edge of a locking groove on the stop roll, the locking screw nearest the master stop will line up automatically with the next locking groove.
3. Screw down the first lock screw, at the same time pressing the stop dog toward the head end of the machine.
4. Screw down the second lock screw and then adjust the stop screw until it moves the master stop back to a point where the feed lever knocks off. Then tighten the center screw to bind the stop in position.

Feed Train

The feed train transmits power from the spindle of the machine to the cross slide and hexagonal turret. The feed

train consists of a head end gear box, a feed shaft, a square turret carriage apron or gear box, and an hexagonal turret apron or gear box. Figure 3–5 illustrates the turret lathe feed train.

The number of different feeds possible varies from 6 to 16, depending upon the size and model of machine. On any machine, select first a range of POSSIBLE feeds by shifting or changing the gears in the head end gear box. Then shift the levers in the aprons to select the particular feed.

Grinding and Setting Cutters

There are five types of material commonly used for cutters—carbon tool steel, high-speed steel, Stellite, carbides, and diamonds.

CARBON TOOL STEEL can be easily ground and hardened. It is inexpensive and will take a keener edge than any other type of cutter. Carbon tool steel is preferred for fine finish or brass because it will produce a very smooth finish.

HIGH-SPEED STEEL is the most commonly used steel for cutters because it can be run at twice the speed that carbon tool steel will take.

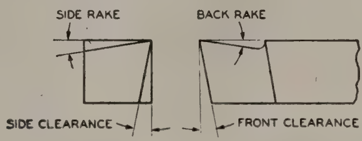
Three types of high-speed steel are used: (1) standard, or 18–4–1, (2) molybdenum high-speed steel, and (3) super high-speed steel. Molybdenum and 18–4–1 are used for general machinery cuts, while super high-speed is used for machining the harder and tougher grades of steel.

STELLITE, an alloy of several metals, mostly chromium and cobalt, is used extensively for machining cast iron, malleable iron, and hard bronzes. Stellite can be run 50 percent faster than high-speed steel.

CARBIDE cutters are made of mixture of very small, hard particles of carbides of tungsten, tantalum, or titanium imbedded in a softer but very tough material that gives body to the mass. They can be run 1½ to 4 times faster than high-speed steel and are almost as hard as diamonds. Carbide cutters, although they will ordinarily run a long time

without regrinding, break very easily if bent, and for that reason are used only in the form of small tips brazed to large steel shanks.

Diamonds are used as cutters on small high-speed turret lathes to machine hard rubber, bakelite, pressed carbon, aluminum, and brass. The diamond is secured in the end of a tool bit by brazing. The surrounding metal is then ground away to expose the diamond tip, which is ground and lapped to regular cutting angles.



Material	Side Clearance Angle	Front Clearance Angle	Back Rake Angle	Side Rake Angle
Cast Iron	8°	8°	8°	14°
Copper	8°	8°	10°	25°
Brass, Soft	8°	8°	0°	0°
Hard Bronze	8°	8°	6°	5°
Aluminum	8°	8°	8°	18°
Steels:				
SAE X1112 Spec. Screw Stock	8°	8°	15°	20°
SAE X1315 Screw Stock	8°	8°	15°	20°
SAE 1020 Carbon Steel	8°	8°	15°	15°
SAE 1035 Carbon Steel	8°	8°	15°	15°
SAE 1045 Carbon Steel	8°	8°	10°	12°
SAE 1095 High Carbon Steel	8°	8°	5°	10°
SAE 2315 Nickel Alloy	8°	8°	15°	15°
SAE 2335 Nickel Alloy (Annealed)	8°	8°	15°	15°
SAE 2350 Nickel Steel (Annealed)	8°	8°	10°	12°
SAE 3115 Nickel Chromium Alloy	8°	8°	15°	15°
SAE 3140 Nickel Chromium (Annealed)	8°	8°	10°	12°
SAE 3250 Nickel Chromium (Annealed)	8°	8°	8°	12°
SAE 4140 Chrome Moly	8°	8°	10°	12°
SAE 4615 Nickel Moly	8°	8°	15°	15°
SAE 6145 Chrome Vanadium	8°	8°	8°	12°

Figure 3–6.—Tool angles.

The angles recommended in figure 3–6 are figured with the cutter operating on center with the work. That is, the angles given for the cutter are based on the assumption that the body of the cutter is held parallel to a line drawn through the cutting edge and the center of the work. When cutters are raised above center on small diameters the front clearance angle will almost disappear, and the back rake angle becomes too great, resulting in heavy rubbing at the clearance angle. (See fig. 3–7.) If the cutter is mounted in a square turret, you can bring it to center by using either shims or rockers.

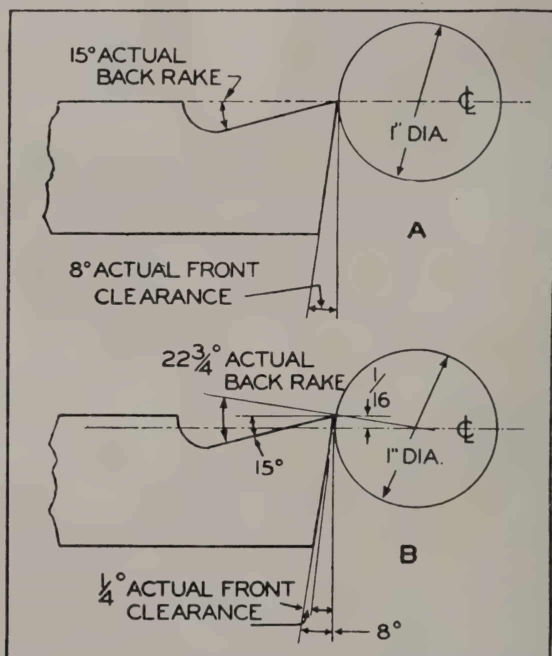


Figure 3–7.—Cutters above center on small diameters.

Maintaining Proper Angles.—If rockers are used in a square turret, you must change the rake and clearance angle (see fig. 3–6) when you grind the cutter, in order to compensate for the changed position of the cutter. The problem

caused by rocker adjustments can be taken care of by starting out with top rake angles greater than required and decreasing these angles as the cutter is reground and adjusted to center. It is especially recommended that shims be used with carbide cutters, because the angles do not change as the cutter is reground and proper clearances and rakes are more easily maintained. Figure 3–8A illustrates the use of rockers, and figure 3–8B illustrates the use of shims.

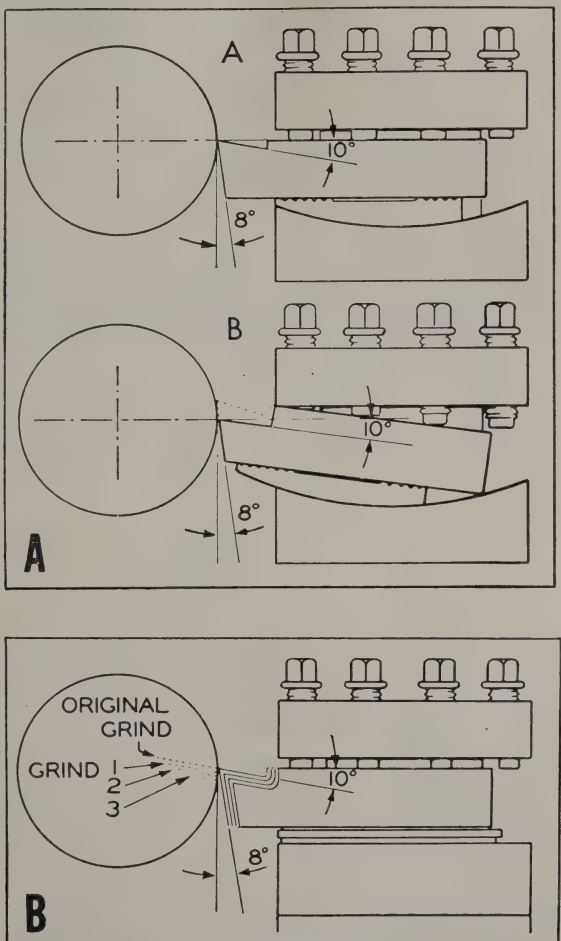


Figure 3–8.—A. Use of rockers. B. Use of shims.

Controlling Chips.—Chips can be controlled in two ways: (1) by getting the right combination of back and side rake angles in combination with speeds and feeds, and (2) by grinding a curling groove in the cutter. Method (1) is usually the best way. By changing the angle slightly, it is possible to throw chips in one direction or the other. If you use method (2), start the groove in back of the cutting edge but do not carry it through the point of the cutter. A groove through the point of the cutter will tend to break down the cutting point, will produce a poor quality finish, and may produce a double chip. (See fig. 3–9.)

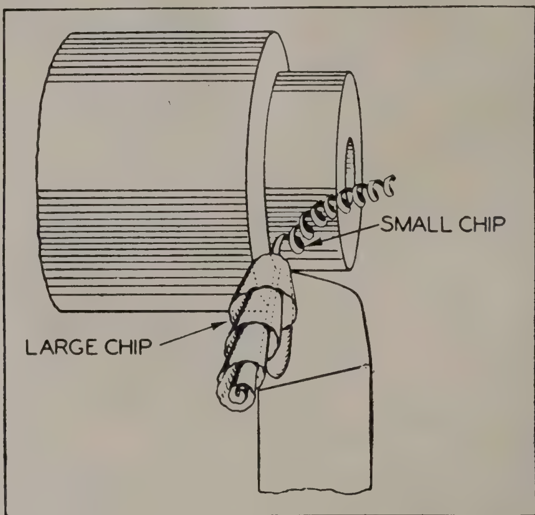


Figure 3–9.—Double chip caused by improper curling groove.

Coolants.—Using coolants makes it possible to run the lathe at higher speeds, take heavier cuts, and use cutters for longer periods without regrinding, thus getting maximum service from the lathe. Coolants flush away chips, protect machined parts against corrosion, and help in giving a better finish to the work. A coolant also makes for greater accuracy by keeping the work from overheating and thus becoming distorted. Figure 3–10 illustrates the incorrect and the correct method of applying cutting oil or coolant.

Turning

The principle previously described for cross slide and multiple turning cutter heads is also used in grinding bar turner cutters, the one difference being that bar turner cutters are ground on the top rather than on the side. The only additional problem involved is positioning and adjusting the rolls.

Any discussion of the grinding and setting of bar turners should take up the nomenclature of the bar turners themselves.

Bar turners are held on the hexagonal turret, and combine in one unit a cutter holder and steady rest that travels with the cutter and supports the workpiece. This roller rest holds the work against the cutter, permitting the taking of deep cuts at heavy feeds.

Steady rests on bar turners are usually equipped with rollers to eliminate wear and make high-speed operation possible. Bar turners equipped with **V** back rests are used

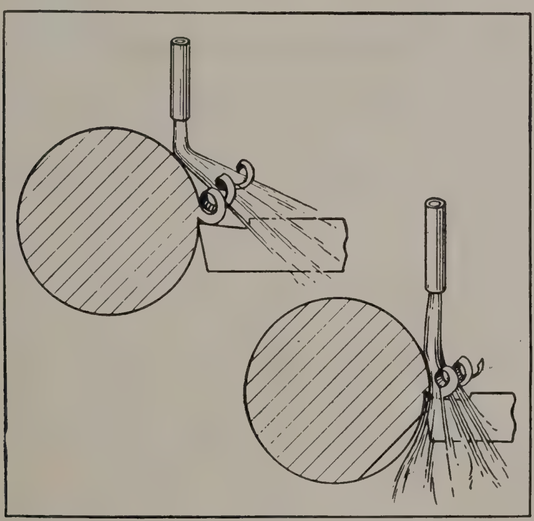


Figure 3–10.—The incorrect (left) and the correct (right) methods of applying coolant.

for turning brass where there is no problem of wear, and where small chips might get under rollers and mark the workpiece.

On the ROLLER-TYPE TURNER the rollers may be either ahead of or behind the cutter. If they are behind the cutter, they burnish the workpiece. This burnishing is often an important factor, inasmuch as it may eliminate the need of polishing or grinding operations. When a diameter is turned so that it is concentric with a finished diameter, the rolls are run ahead of the cutter on the previously finished surface. Figure 3–11 illustrates rolls behind and ahead of cutter.

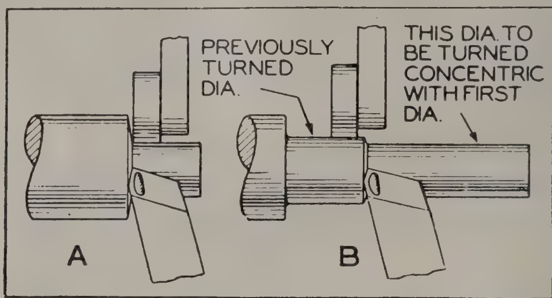


Figure 3–11.—Rolls behind (A) and ahead (B) of cutter.

The rolls on the universal turner are set ahead of or behind the cutter by adjusting the movable cutter, with the rolls remaining in fixed position. The universal bar turner is illustrated in figure 3–12A. Another type of turner (fig. 3–12B) has adjustable roll arms; the cutter is fixed, and the rolls can be moved ahead of or behind the cutter.

The steps in setting up the single cutter turner are as follows:

1. Extend the bar stock about 1½ in. to 2 in. from the collet. Then, with a cutter in the square turret on the cross slide, turn the bar to 0.001 in. under the size desired for a length of ½ in. to 1 in.
2. With the roll jaws swung out of position (see fig. 3–13A), and with the cutter set above center, adjust the cutter slide of the turner against the turned portion of

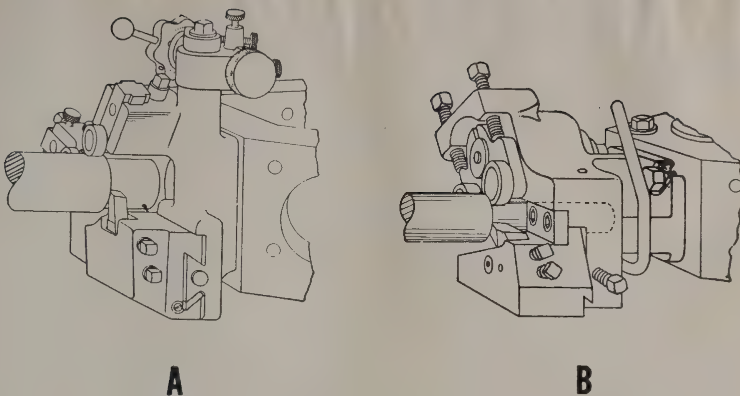


Figure 3–12.—A. Universal bar turner. B. Single bar turner.

the bar stock and rub a shine mark on the turned portion, as indicated in figure 3–13B.

3. Set the cutter at the center of the shine mark, clamp the cutter tightly in its slide, turn the spindle to move the shine mark away from the cutter point, and adjust the slide until the cutter is 0.0015 in. from the turned diameter. You now have the cutter set, and the rolls should be positioned endwise and adjusted to size.
4. Align the rolls with the back of the point radius of the cutter, as shown in figure 3–14. Adjust the rolls by means of clamping screws, and then clamp tightly. The

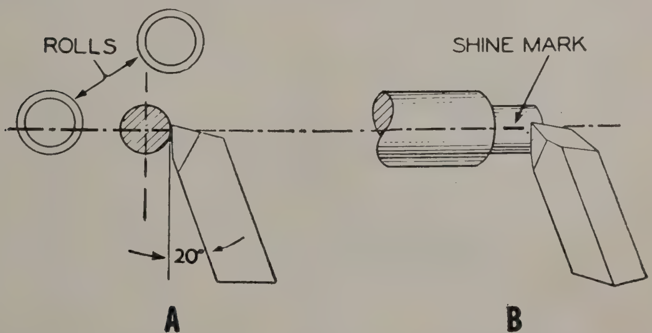


Figure 3–13.—Rubbing a shine mark to establish center. A. Roll jaws out of position. B. Shine mark on turned portion.

rolls are in proper adjustment when LIGHT PRESSURE WILL STOP THEM FROM TURNING as the bar stock is revolved.

5. Push the cutter to cutting position by means of the withdrawal lever and take a trial cut. If you have a proper set-up the size will be accurate to ± 0.001 in.

Tips on Bar Turning

1. To prevent marking the work as you bring back the turret, always use the withdrawal lever before the return stroke of the turret.
2. When rolls are set to follow the cutter, it is usually true that the heavier the cut the better the finish. The heavier the cut the greater the pressure is against the rolls, and thus the greater the burnishing action.
3. If you are using light cuts, special rolls with a steep taper will sometimes produce a better finish.
4. Regardless of the deepness of cut, there are three factors that must be watched if you want to obtain a high grade finish: (1) the faces of the two rolls must be in line, (2) the leading corners of the rolls must be perfectly round and exactly equal, and (3) end play in the rolls should not exceed 0.003 in.

Boring

Two general types of boring cutters are used—tool bits held in boring bars, and solid forged boring cutters. Tool

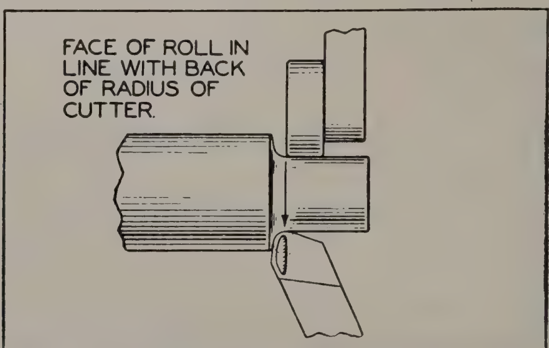


Figure 3–14.—Roll aligned with cutter.

bits held in boring bars are most common because this combination is inexpensive and provides great flexibility as to sizes and types of work that can be accomplished. Solid forged cutters, however, are used to bore holes too small to be cut with a boring bar and inserted cutter.

The cutter in a STUB BORING BAR is held either at right angles to the bar, or extending beyond the end of the bar and at an angle. This extension of the cutter beyond the end of the bar makes it possible to bore up to shoulders and in blind holes. The angular cutting bar also has the added advantage of an adjusting screw behind the cutter.

When the stub boring bar or forged boring bar is used, the overhang should be as short as the hole and the set-up will permit. You should always select the largest possible size of boring bar, in order to give the cutter as rigid a mounting as possible, and you should never extend the boring cutter farther than is actually necessary. To increase the rigidity of small stub boring bars, sleeves can be employed to regulate the amount of overhang. The increased rigidity makes for more accurate work and allows for heavier feeds.

The HEXAGON TURRET is ordinarily used when making boring cuts, although, if necessary, boring tools can be held on the cross slide. The advantages of taking a boring cut from the hexagon turret are:

1. Turning or facing cuts may be taken with the cross slide at the same time that a boring cut is taken from the turret.
2. Boring cutters can be combined with turning cutters held in multiple or single turning heads.
3. The boring cutter is held in a fixed position and needs no adjusting as to size each time a cut is made.

BORING PRACTICE.—Boring feed can be increased by using a boring bar with two cutters, which is an advantage when a quantity of like pieces are required. It is good practice when using double cutters to rough bore with a piloted boring bar in order to obtain rigidity for heavy feeds, and then to finish the hole with a stub boring bar held in a slide tool.

Piloted boring bars require a machine with a long stroke—the saddle type—in order that the turret may be moved far enough to pull the piloted bars from the pilot bushing and work before indexing the turret. Usually where the pilot bushing is mounted in the chuck close to the work, the effective travel of the turret must be about 2½ times the length of the workpiece.

Grinding boring cutters is the same in principle as grinding turning cutters, the only difference being that the boring cut is on the inside, instead of the outside, of the work. The side or front clearance angles, therefore, are greater, to prevent rubbing. However, the clearance angle must not be too great, or the cutting edge will be too sharp-pointed and will break down because of the heat of friction. The exact amount of front clearance angle will depend on the size of the hole you are boring. The smaller the hole, the more clearance required. There are no set rules for exact clearance angles; knowledge of what will be the best angle comes with experience in operating the lathe.

You can set cutters below center to prevent withdrawal marks.

To true up an out-of-round hole properly, it is best practice to take two or three light cuts rather than one heavy cut. This leaves little work for the reamer and results in a smooth, accurate job.

Forming

One of the fastest methods of producing a finished diameter or shape is by forming. In planning a set-up, you should study the work to determine if forming tools can be used. It is possible, on many jobs, to combine two or more cuts into one operation by using a specially designed forming cutter. Forming cutters are also used to produce irregular and curved shapes that are difficult to produce in any other way. The following types of forming cutters are used:

1. Forged forming cutters are ordinarily mounted directly in the square turret or tool post and are the least ex-

pensive to make. They have, however, the shortest productive life.

2. Dovetail forming cutters are held in tool holders mounted on the cross slide. Their shape or contour is machined and ground the full length of the face, and the cutters are set in the holder at an angle, to provide front clearance. When the cutter wears, only the top need be reground. Dovetail cutters cost more than forged cutters, but they have a longer productive life, are more easily set up, maintain their form after grinding, and are more rigid and can be operated under heavier feeds.
3. Circular forming cutters have an even longer life than dovetail cutters. The shape of circular cutters is ground on the entire circumference and, as the cutting edge wears away, the top is reground. After grinding, the cutter is moved to a new cutting position by rotating the cutter about its axis. (See fig. 3–15.)

Grinding Forming Cutters.—You should NEVER regrind circular forming cutters on a bench grinder. They should

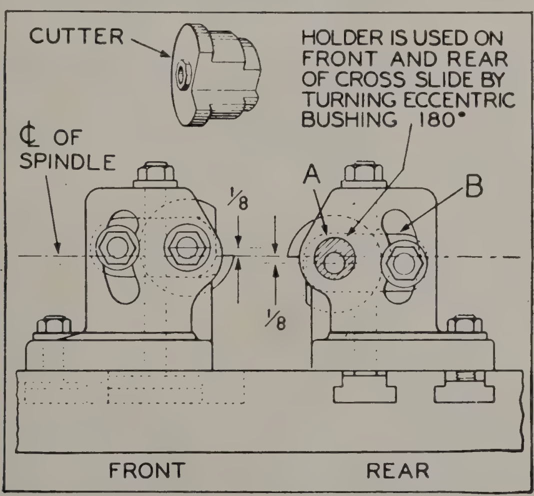


Figure 3–15.—Circular cutter diagram.

be reground on a toolroom grinder, where they can be rigidly supported and ground to maintain the original relief angles.

Threading

For turret lathe operations, DIES and TAPS provide a means of cutting threads easily and quickly, and usually in only one pass over the work. Dies and taps for turret lathes are divided into three general types: solid, solid adjustable, and collapsing or self-opening.

SOLID TAPS and DIES are usually held in a positive drive holder having an automatic release. A longitudinal floating action (not to be confused with the floating dieholder) allows the tap or die to follow the natural lead of the thread, which obviates having to depend on a delicate "feel" to produce results. Solid dies are used only when the thread to be cut is too coarse for the self-opening die head or a solid adjustable die head, or when the tool interferes with the set-up.

The SOLID ADJUSTABLE TAPS and DIES should be used in place of collapsing taps and self-opening die heads only when speed is low, and when time required for backing out is not important.

COLLAPSING TAPS are used for internal threading. They are timesavers, inasmuch as it is not necessary to reverse the spindle in order to withdraw the tap. The pull-off trip type, which is collapsed by simply stopping the feed, is the most frequently used.

Various types of SELF-OPENING DIE HEADS are used. Some have flanged backs for bolting directly to the turret face; others have shanks which fit into a holder. The die heads are fitted with several different types of chasers; the tangential and circular type chasers can be ground repeatedly without destroying the thread shape. They are a bit more difficult to set, but they are better adapted than flat chasers would be for long runs of identical threads.

Die heads are supplied either with a longitudinal float or with a rigid mounting, and may be the pull-off, outside, or inside trip type. The floating type die head should be used

for heavy duty turret lathe work, for fine pitch threading, or for finishing rough-cut threads.

On some types of work it is necessary to take both roughing and finishing cuts. They are normally taken when threading a tough material, or when a smooth finish is required. Some types of die heads are equipped with both roughing and finishing attachments; if such die heads are not available, roughing and finishing cuts can be taken with separate dies or taps set up on different turret stations.

The LUBRICANTS USED FOR THREADING and the materials with which these lubricants are used are as follows:

Soluble oil or cut dry	Cast iron.
Soluble oil	Malleable iron.
Soluble oil	Wrought iron.
20 percent mineral lard oil	Steel.
Kerosene	Aluminum.
Paraffin oil	Brass or Bronze bar.

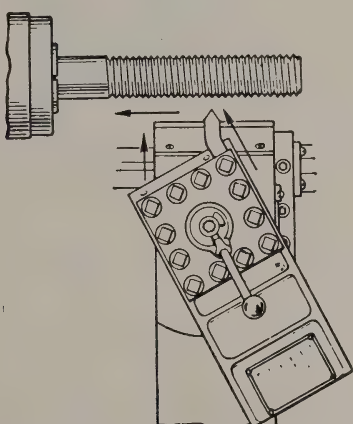


Figure 3–16.—Compound cross slide threading.

THREAD CHASING PRACTICE.—Two different methods of producing threads with a single-point cutter are used on turret lathes. The first method is to obtain an angular feed to the cutter by means of the compound carriage (fig. 3–16) or by using the angular threading tool (fig. 3–17). By the first method, the cutter is fed straight into the work by

means of moving the main slide. The second method is to feed the cutter straight into the work for each pass, as indicated in figure 3–18. With this latter method you apply by hand a slight drag to the carriage or saddle during the roughing cut, and remove the drag during the final polishing passes. It takes more skill to use this second method, but it produces good threads.

Taper Turning

Producing tapers with a turret lathe may be done with (1) forming cutters, (2) roller rest taper turners, or (3) taper attachments.

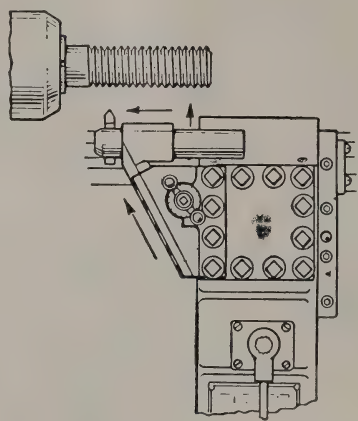


Figure 3–17.—Adjustable tool holder threading.

FORMING CUTTERS of the forged, circular, or straight dovetail types may be used to produce tapers when the workpiece is rigid enough, or can be supported in such a way that it will withstand the heavy forming cut. If work cannot be formed, other methods (described later) must be used.

Forming work with forming cutters should be accomplished only when the following conditions are met:

1. The work must support the forming cut without chatter, and if it does not, a center support must be used.
2. The finish must meet requirements.

3. The taper angle must be accurate.

It is best to use the ROLLER REST TAPER TURNER for bar jobs having long tapers. This tool can be quickly set for size by means of the graduated dial, and the angle of taper can be controlled accurately by the taper guide bar.

TAPER ATTACHMENTS are provided for the cross slides of most turret lathes of both ram and saddle type. They are also provided for the cross-sliding hexagon turrets on the saddle type machine. These attachments are quickly set to produce either internal or external tapers, and do not interfere with normal operation when they are not in use. Most taper attachments are of the movable type and can be quickly located at any desired bed location.

Taper attachments all have a pivoting guide plate which can be adjusted to any required taper angle. Figure 3–19 shows a ram type taper attachment in detail.

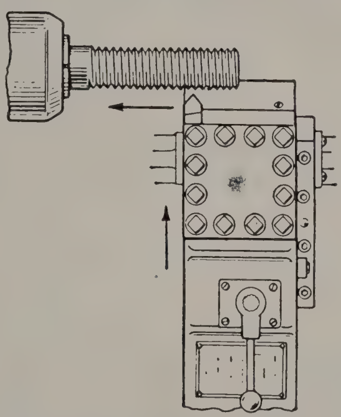


Figure 3–18.—Straight-in feed threading from the square turret.

The taper attachment illustrated in figure 3–19 is broken down for study as follows:

a. The guide plate (1) pivots on the base plate (2), which slides in carrier plate (3).
b. When the attachment is to be used, the extension rod (4) is clamped to the machine with the setscrew (5), and the binder screw (6) is loosened.

c. The stop collar (7) and the latch (8) can be used for locating the cross slide unit on the bed of the machine. To use the stop collar and the latch, move the cross slide unit to the left until the stop collar comes in contact with the latch. This locates the entire unit.

Taper attachments are fitted with a backlash eliminator nut (see fig. 3–19) for the slide screws. Tightening this nut against the feed screw removes all play between feed screw and nut.

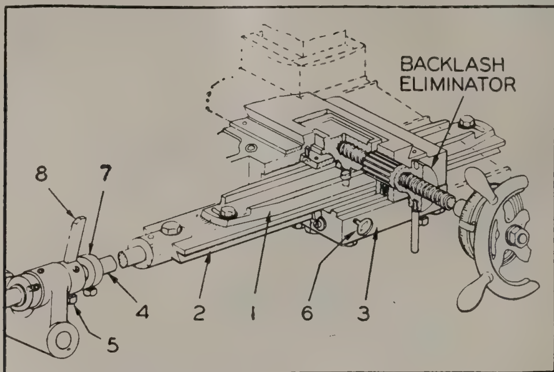


Figure 3–19.—Detail of cross slide taper attachment for saddle type machine.

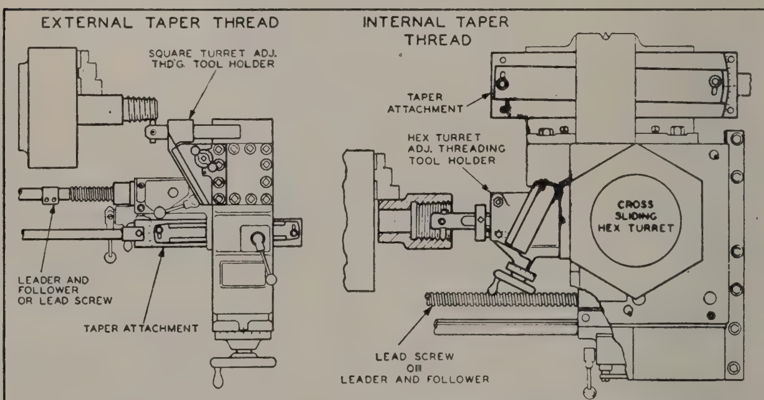


Figure 3–20.—Using a taper attachment in connection with a thread chasing attachment.

Maintaining Accurate Sizes.—In order to duplicate and maintain accurate sizes when using a taper attachment with other tools in a set-up, three things are vitally necessary: (1) the attachment must be located accurately in the same position in relation to the cross slide each time it is used, (2) the cross slide must be located in exactly the same spot on the bed when the extension rod is clamped with the setscrew and the binder screw is loosened, and (3) when the binder screw is tightened and the extension rod is loosened, the cross slide must be in exactly the same position as in step (1) above.

Taper Threading.—Either internal or external threads can be produced with the taper attachment in conjunction with a lead screw thread chasing attachment. (See fig. 3–20.)

Collets, Arbors, and Chucks

The connecting links between the turret lathe and its tools, the work-holding devices, must be considered carefully if you are to produce accurate finish jobs.

Collet chucks are used for bar stock up to 2½ in., and are the spring collet type. Collet chucks for bar stock over 2½ in. are the parallel closing type. Since most bar stock jobs fall below the 2½ in. stock size, the spring collet type is most common. Spring collets are of three types—the pushout, the drawback, and the stationary. Figure 3–21 illustrates the pushout type where plunger A, when moved to the right, forces the partially split tapered end of collet D to the hood C, which causes the collet to tighten about the bar stock. The drawback type collet operates in the same way as the pushout type, except that the collet is drawn back against a tapered hood for tightening (see fig. 3–22). Stationary type collets do not move endwise. The plunger and collet sleeves are tapered, and the collet is held in place by the shoulder on the collet which comes into contact with the hood (see fig. 3–23).

Arbors.—Three types of arbors are used on horizontal turret lathes: (1) expanding bushing type, (2) expanding plug type, and (3) threaded arbors. They can be mounted

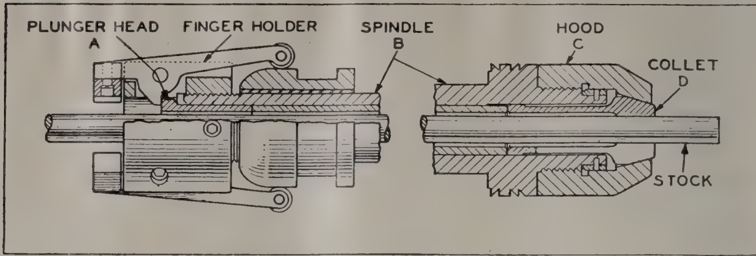


Figure 3–21.—Pushout type collet chuck mechanism.

on either the plain or adjustable type adapter hoods. The adjustable type adapter hood, however, provides a means of more accurately aligning the adapter with the spindle, and is the type most commonly used.

The expanding bushing type arbor is best suited for large diameters and for roughing work. Figure 3–24 illustrates the expanding bushing type arbor, in which the workpiece A is fitted against stop plate B; as drawrod C is pulled back, the expanding split bushing D climbs the taper, expanding to where it grips the work. This type of arbor bushing grips the work over the entire bushing length, even where there are slight size variations.

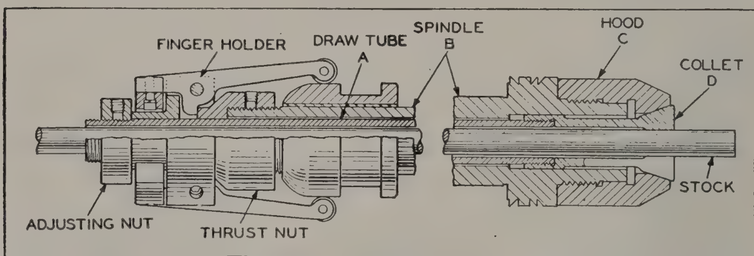


Figure 3–22.—Drawback type collet chuck mechanism.

The expanding plug type arbor is used for light finishing cuts where accuracy is more important than gripping power. In figure 3–25, A represents the workpiece fitted against stop plate B; and as drawrod C is pulled back, the partially split plug D is forced to expand at its outer end until it grips the

workpiece A. This type of arbor grips the work only at its outer edge.

With the threaded type arbor, the work is held on a previously machined thread. The workpiece is screwed to the arbor when the chuck lever is in a closed position, and the pressure of the cut tightens the workpiece. The work is removed by unscrewing the workpiece after the draw tube is released.

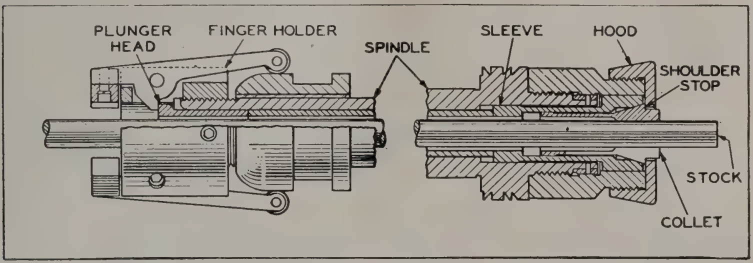


Figure 3–23.—Stationary type collet chuck mechanism.

CHUCKS are placed in three classes: (1) universal chucks of the geared scroll, geared screw, or box chuck type, where all 3 jaws move at the same time, (2) independent chucks, where each of the jaws is operated independently, and (3) combination chucks, where each jaw may be operated independently, but where all jaws can be moved as a group.

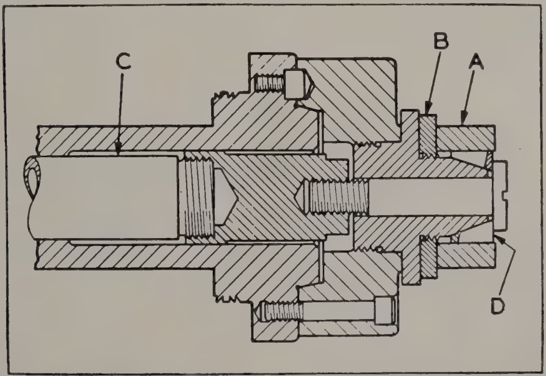


Figure 3–24.—Expanding bushing type arbor.

The TWO-JAW BOX CHUCK is used mostly for holding small work of irregular shape. The jaw screw operates both jaws at the same time. Chuck jaws of various shapes may be secured to the master jaws with an adapter of the dovetail, crosskey, or other form, depending on the standard use in the particular machine shop in which you are working.

The THREE-JAW GEARED SCROLL CHUCK is used more than any other type. With standard jaw equipment it holds work of regular shape, and may be adapted for holding irregularly shaped work.

The horizontal turret lathe is provided with COMBINATION CHUCKS which have 2-piece master jaw construction, and an independent jaw screw between the sections. The bottom or master part of the jaw is moved by the scroll, and the top part by the independent jaw screw. These chucks are used mostly to hold irregular-shaped work or when a jaw needs to be offset from a true circle. The combination chuck provides a means of truing work on first chuckings by the use of the independent movable jaws. The same chuck can then be used for second operations, by using the geared scroll to operate the jaws when gripping on a finished diameter.

Tooling Principles

The aim of a good turret lathe operator is to tool the machine and operate it in such a manner so that a job can

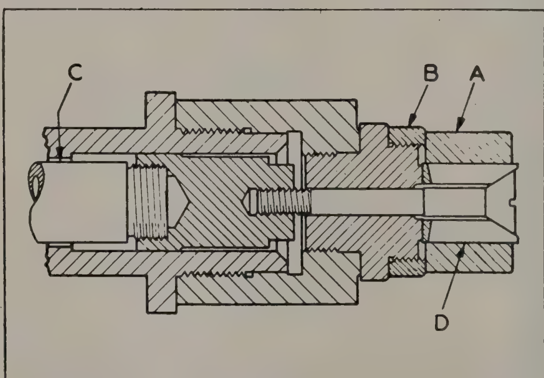


Figure 3–25.—Expanding plug type arbor.

be turned out as rapidly and as accurately as possible. The successful Machinery Repairman will, in regard to turret lathe operation, always keep in mind the following factors:

1. Keep the total time for a job at a minimum by balancing set-up time, work-handling time, machine-handling time, and actual cutting time.
2. Reduce set-up time by using universal equipment, and by arranging the heavier flanged type tools in a logical order.
3. Select proper standard equipment, and use special equipment only when it is justified by the quantity of work to be produced.
4. Reduce machine-handling time by using the right size machine, and by taking as many multiple cuts as possible.
5. Reduce cutting time by the following methods: (1) taking two or more cuts at the same time from one tool station, (2) taking cuts from the hexagon turret and the cross slide at the same time, and (3) increasing feeds by making the set-up as rigid as possible by reduction of tool overhang and use of rigid tool holders.
6. Never block off stations on the square turret. (See figs. 3–26 and 3–27.)

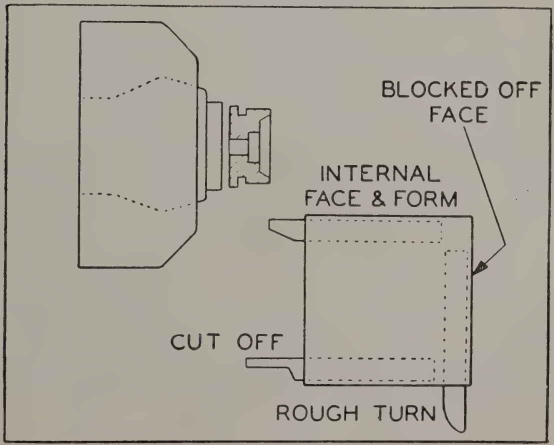


Figure 3–26.—Square turret with one face blocked off.

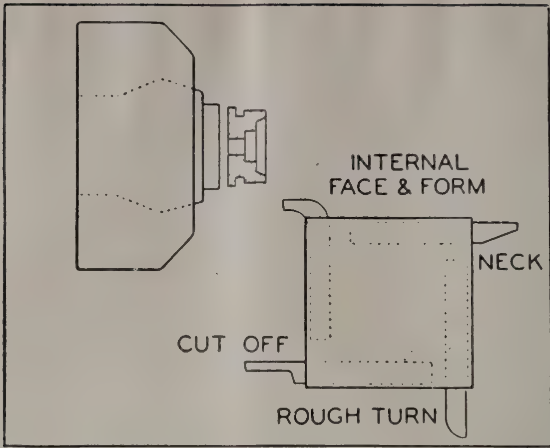


Figure 3–27.—Square turret with all four stations in use.

7. Refrain from clamping the saddle of a ram type machine in such a position that any station cannot be indexed. The longest tool on the turret should govern the position of the saddle.
8. Never take a tooling set-up for granted. Almost every job can be done in several different ways. Always study the work to determine if the set-up can be improved.

VERTICAL TURRET LATHE

Like the horizontal turret lathe, the vertical turret lathe plays an important role in machine shop operations. The vertical turret lathe is used mostly for machining circular castings that are of such size that they cannot be conveniently machined in a horizontal turret lathe. The operations, however, are very similar to those performed in the horizontal lathe, the only difference being in the position in which the workpiece is held. In the horizontal lathe the workpiece is held vertically in place by means of a face plate or chuck, while in the vertical turret lathe it is placed on a horizontal table. The vertical turret lathe is in reality the headstock of the horizontal turret lathe, with the spindle held in a vertical instead of horizontal position.

Types

Two TYPES of vertical turret lathes are used—the single table type, and the double table type. The single table type is the one most used in a Navy machine shop. The TOOLS used on the vertical turret lathe differ very little from those used on the horizontal lathe, the main difference being in the shape that is required to perform the various jobs. Tools

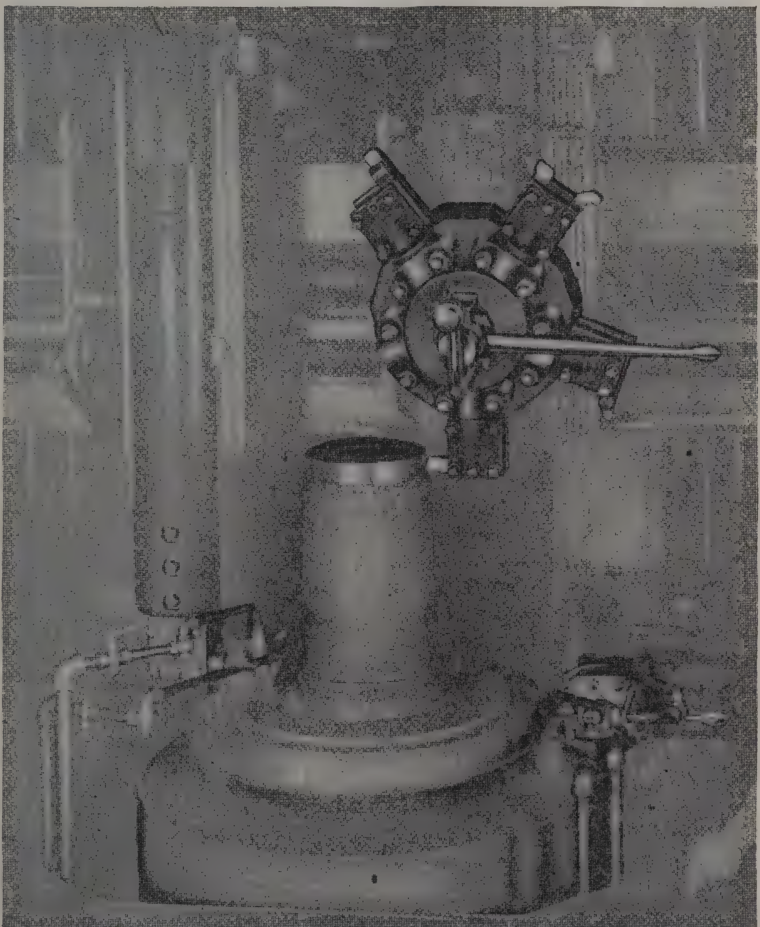


Figure 3–28.—Taper turning on a vertical turret lathe.

used are roughing, finishing, and parting, which are available straight or bent, and right- and left-hand as required. Radius and forming tools of various kinds are also used.

The vertical turret lathe is equipped with a SIDE HEAD. This head is analogous to the cross slide of the horizontal turret lathe. The location of the side head permits simultaneous machining adjacent to the operations performed by the main turret, without interference or lost time between cuts. Controls are convenient, and its perfect counterbalance serves to make vertical manual movement quick and easy. Vertical and horizontal feeds are provided with simple and accessible feed changes and controls.

Mounting the Workpiece

The method of mounting the workpiece on the table of the vertical turret lathe, though much easier than the mounting on a horizontal lathe, is most important; in many cases it is the determining factor in the quality and quantity of work produced. The workpiece is usually carried in chuck jaws, but may in some instances be secured to the table itself, or carried in special fixtures.

Taper Turning

A simple method of taper turning on the vertical turret lathe is shown in figure 3–28. The taper block is located properly for accuracy of finished dimensions by the "observation stops" mounted on the micrometer dials on the feed rod and screw.

Machining Stock

Figure 3–29 illustrates the machining of SOLID STOCK. The main head operations are drilling, rough boring, first and second ream with a chamfer, or burring operation. At the same time the side head takes a rough and finish face, chamfer, and rough and finish turn. The sequence of these operations, and the use of side and main heads, illustrate the productive possibilities of the vertical turret lathe.

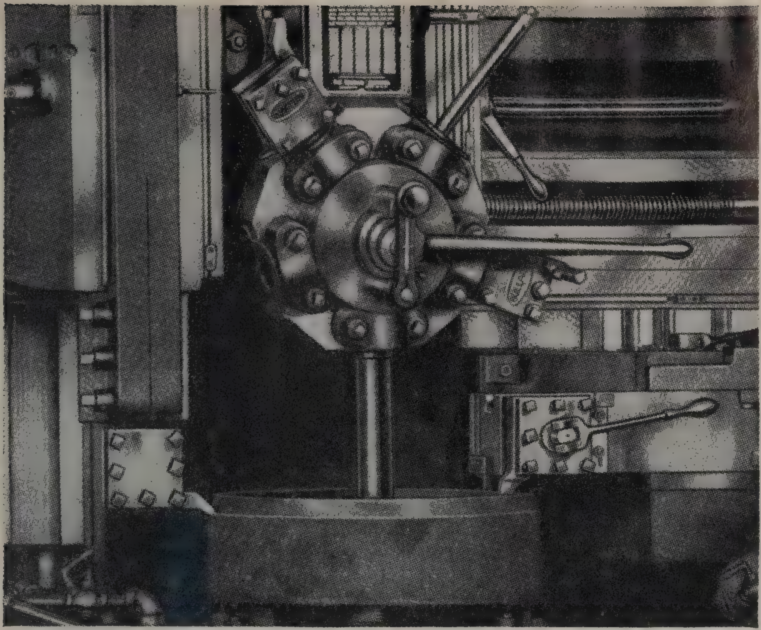


Figure 3–29.—Machining solid stock on a vertical turret lathe.

Double tooling is illustrated in figure 3–30. The set-up for this job is simple and efficient. The double tooling in several heads permits two operations without expending time for indexing.

Figure 3–31 illustrates the machining of odd-shaped pieces secured in special fixtures clamped to the table. Once the correct center is established with the fixture, each succeeding piece may be easily machined and accurately located.

Rigid Chucking.—Figure 3–32 illustrates the method of machining long work. High jaws mounted on the table provide adequate support during the severe boring, facing, and turning cuts required.

Saving Time Between Cuts.—For making flange couplings run true and square, the single-point tools produce the most accurate work. Where but a few pieces of each size are required, the cross movement of the main turret head is a decided timesaver. (See fig. 3–33.)

BORING MILLS

The boring machine is a specialized machine that has been evolved from a basic lathe form. The type of machine in which the cutting tool is mounted on a horizontal arbor is known as a horizontal boring mill; and the machine in which the boring or facing tool is mounted in the lower end of a ram is generally called a vertical boring mill.

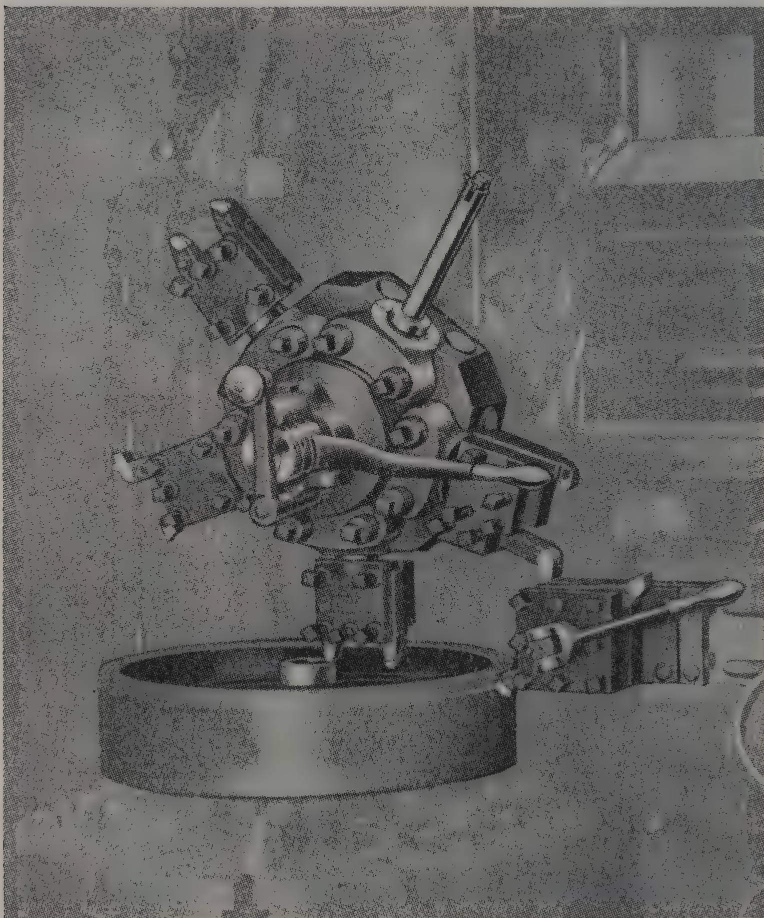


Figure 3–30.—Double tooling.

Horizontal Boring Mill

The horizontal boring mill (fig. 3–34) consists essentially of the boring table (or platen) to which the work is attached, and the horizontal arbor which is supported by a center rest and driven from a headstock to operate the formed tool or fly cutter. It is used for many kinds of shop work, such as facing, boring, drilling, and milling.

When the table, with the work attached, has been posi-

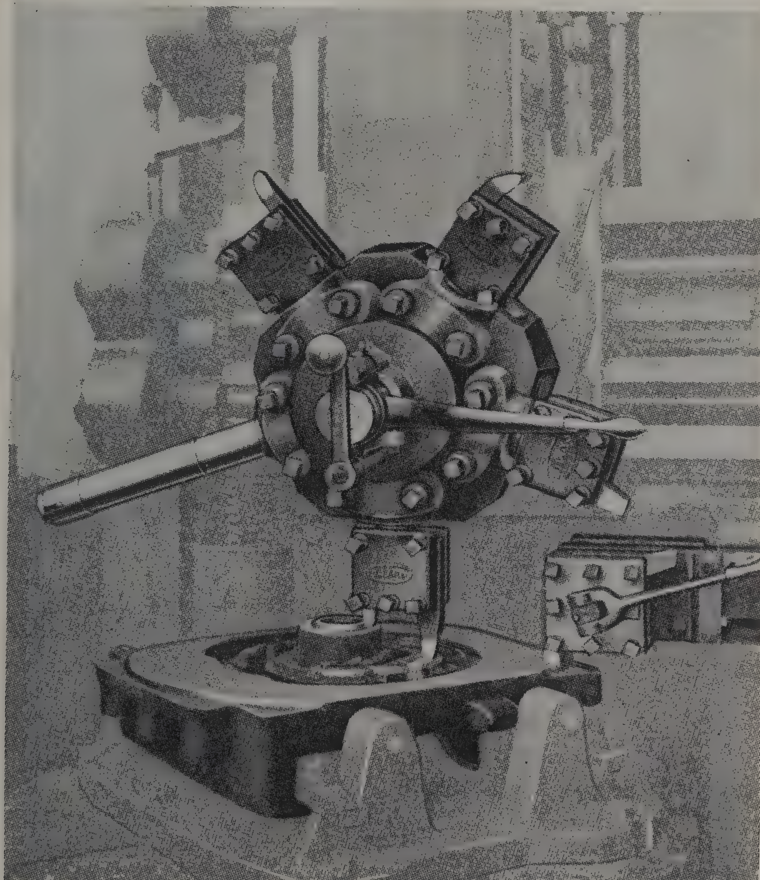


Figure 3–31.—Machining odd-shaped pieces.

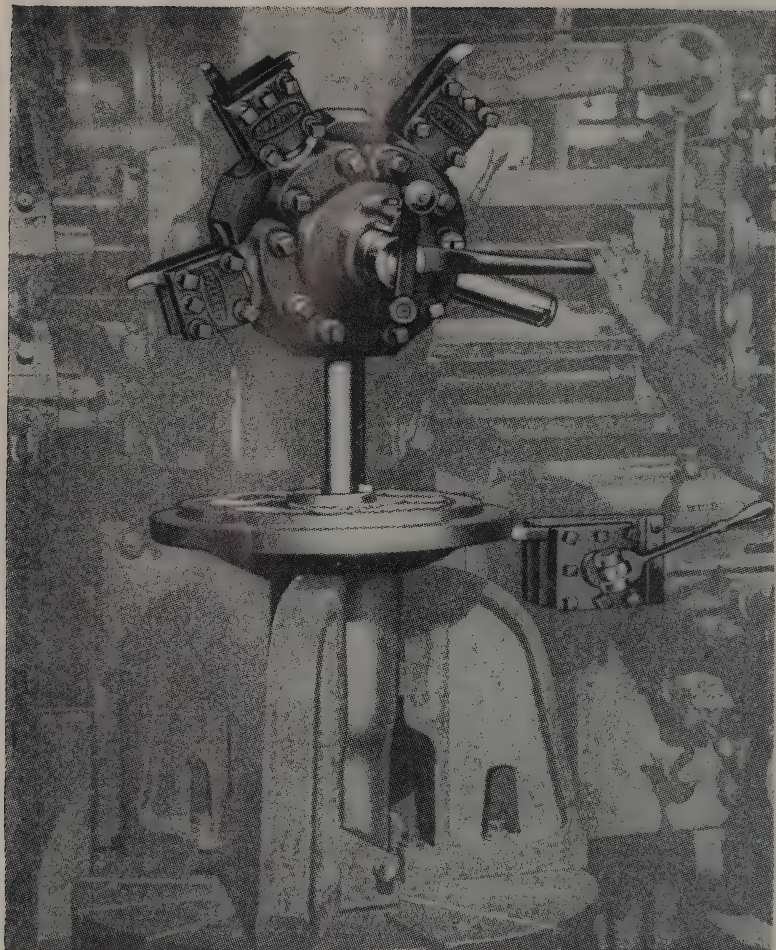


Figure 3–32.—Rigid chucking.

tioned, the boring mill is usually operated by having the arbor and attached tool move relative to the work, which is held stationary. The arbor, driven by the headstock, advances lengthwise as it rotates; the tail block, or center rest, supports it in such a way that, as it rotates, it is fed lengthwise of the bed and through the work. It is also possible to hold the arbor and tool stationary, and to move the table.

To a limited extent, the platen can be power-driven in a direction transverse to the bed of the machine, thus making it possible to bore OVAL holes or slots.

There are two distinct types of horizontal boring mill—the table type, used for small-size work; and the floor type, used for larger-size work, and for the general run of machine shop work.

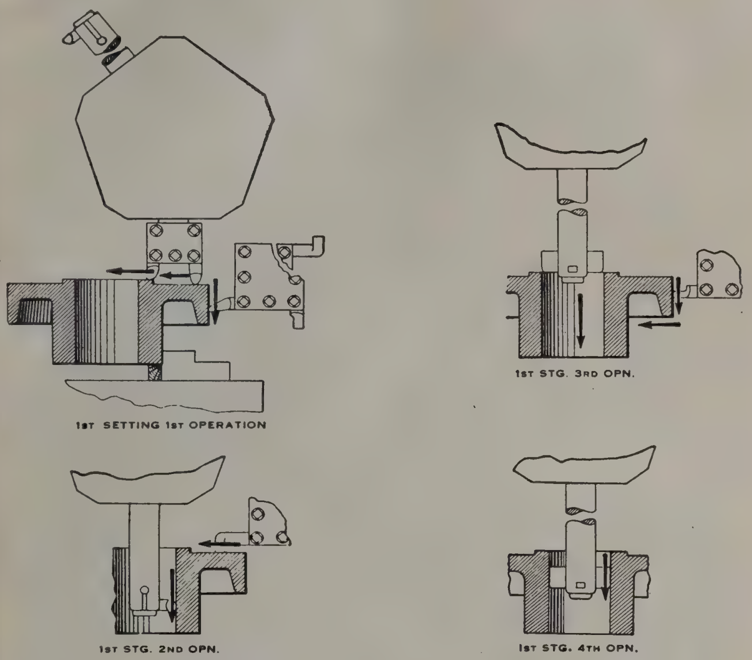


Figure 3–33.—Time-saving between cuts.

The size of a horizontal boring mill is given as the size of the largest bar that the machine is designed to take. A 3-in. boring mill would handle any size bar up to and including one that is 3 in. in diameter. Standard machines are of sizes from 2½ in. up to 10 in., but those most generally used in the Navy are the 3-in., 4-in., and 6-in. machines.

SETTING UP WORK.—The importance of setting up work correctly cannot be too highly stressed; failing to set the work up properly can prove costly in man-hours and ma-

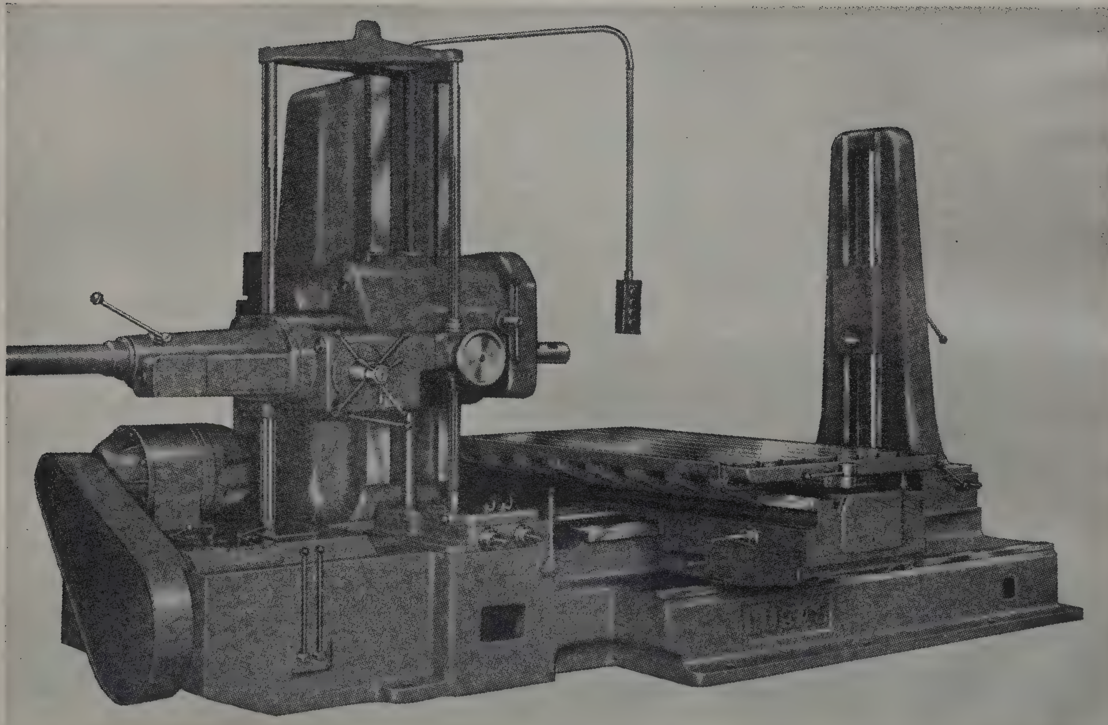


Figure 3–34.—Horizontal boring mill.

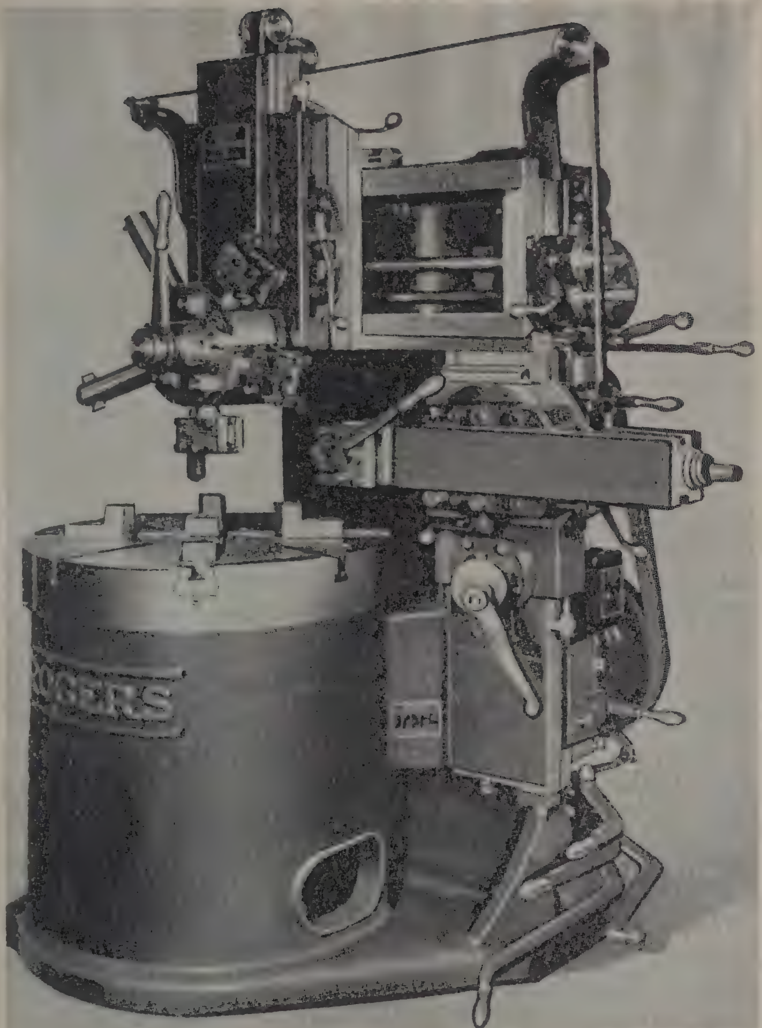


Figure 3–35.—Vertical boring mill.

terial. Oftentimes you will find that it is not advisable to set up a casting to a rough surface, and that it will be preferable to set it up to the layout lines, since these lines will always be used as a reference.

It is important that holding clamps used to secure a piece of work be tight; and if braces are used, they should be placed in such a manner that they cannot come loose. Blocks, stops, and shims should all be fastened securely. If a workpiece is not properly secured, there is always the possibility of ruining the material or the machine, and the risk of causing injury to the machine shop personnel.

Attachments.—Different jobs to be done on the boring mill may require different types of attachments. Such attachments include angular milling heads, combination boring and facing heads, thread lead arrangements, etc. Boring heads are available in a variety of diameters. These circular heads prove particularly useful in large diameter hole boring, since they lend tool support beyond the diameter of the largest bar that can be used on the machine.

Maintenance.—All precision screws for positioning the units are finished with a surface of hard chrome plate. Sliding ways, screws, and bearings of the spindle head, table, and saddle are lubricated by force-feed oiling.

Vertical Boring Mill

The vertical boring mill has a revolving horizontal table to which the work is attached, and which is driven by a constant-duty motor at about 1,150 rpm. The tools for boring, turning, facing, etc., are mounted in the lower ends of the power-driven rams. Figure 3–35 shows a vertical boring mill with a main vertical turret head and a swivel side head.

Some types of machines have two rams mounted on a transverse rail which corresponds to the cross-feed of a lathe carriage. Although it is possible to raise or lower this transverse rail by power drives, the tools are usually advanced by moving the rams; the ram mounts swivel in the heads on the rail, and the tools contact the work on the rotating table. In this way, it is possible not only to generate tapers, but also convex, concave, and other surfaces.

QUIZ

1. What is the chief difference between bar machines and chucking machines?
2. What equipment is sometimes provided on horizontal turret lathes to save time by making it unnecessary to measure each piece when making a number of duplicate parts?
3. What is the purpose of the feed train on the ram and saddle types of horizontal turret lathes?
4. What five types of materials are commonly used for cutters?
5. Why should shims, rather than rockers, be used with carbide cutters?
6. In general, what is the best way to control chips?
7. In what way does the use of a coolant make for greater accuracy?
8. What feature of the roller type turner may eliminate the need for polishing or grinding operations?
9. How can you tell that the rolls on a single cutter turner are in proper adjustment?
10. What are the three factors which must be considered in bar turning in order to obtain a high-grade finish?
11. For what purpose are solid forged cutters used?
12. What is used to regulate the amount of overhang of small stub boring bars, thus increasing the rigidity?
13. Where are boring tools ordinarily held for making boring cuts?
14. In using piloted boring bars, when the pilot brushing is mounted in the chuck close to the work, about how long must the effective travel of the turret be?
15. In grinding boring cutters, what determines the amount of the front clearance angle?
16. What type of forming cutter has the longest productive life?
17. How should circular forming cutters be reground?
18. Why do collapsing taps save time when used for internal threading?
19. What lubricant is used for threading malleable iron?
20. In what three ways are tapers produced on a turret lathe?
21. What tool should be used for bar jobs having long tapers?
22. What are the three types of spring collet chucks?

23. What kind of arbor is used for light finishing cuts, where accuracy is more important than gripping power?

24. What kind of work can usually be done more conveniently on the vertical turret lathe than on the horizontal turret lathe?

25. The side head of a vertical turret lathe is analogous to what part of a horizontal turret lathe?

26. Where is the boring or facing tool mounted on a vertical boring mill?

27. How are oval holes or slots made on a horizontal boring mill?

28. What size bar can be handled by a 4-in. boring mill?

CHAPTER 4

GEARS AND GEAR CUTTING

Gears have always been a highly essential element in the construction of machinery used aboard ships and at naval shore facilities. In the modern Navy, however, the emphasis on speed, power, and compactness in naval machinery has created a special problem for the gear cutter. He must be able to turn out a noiseless, practically unbreakable gear capable of transmitting large amounts of power in small spaces. Making gears of this type calls for skill and precision of a high order.

In some Navy machine shops gear hobbing machines or gear shapers are used for gear cutting. But in most shops, because of the relatively small number of gears that are cut, the milling machine is most often used. The material on gears and gear cutting presented in this chapter, therefore, is limited to cutting practice on a standard milling machine. It is suggested that, whenever you have an especially difficult problem in calculating or cutting gears, you consult a machinists' handbook for more detailed information. Your machine shop office will have books of this nature.

Figure 4–1 shows the 12 types of gears most commonly used. The four types that are ordinarily cut in the machine shop are spur gears, bevel gears, helical gears, and worm gears. Procedures for cutting these four types are described in this chapter.

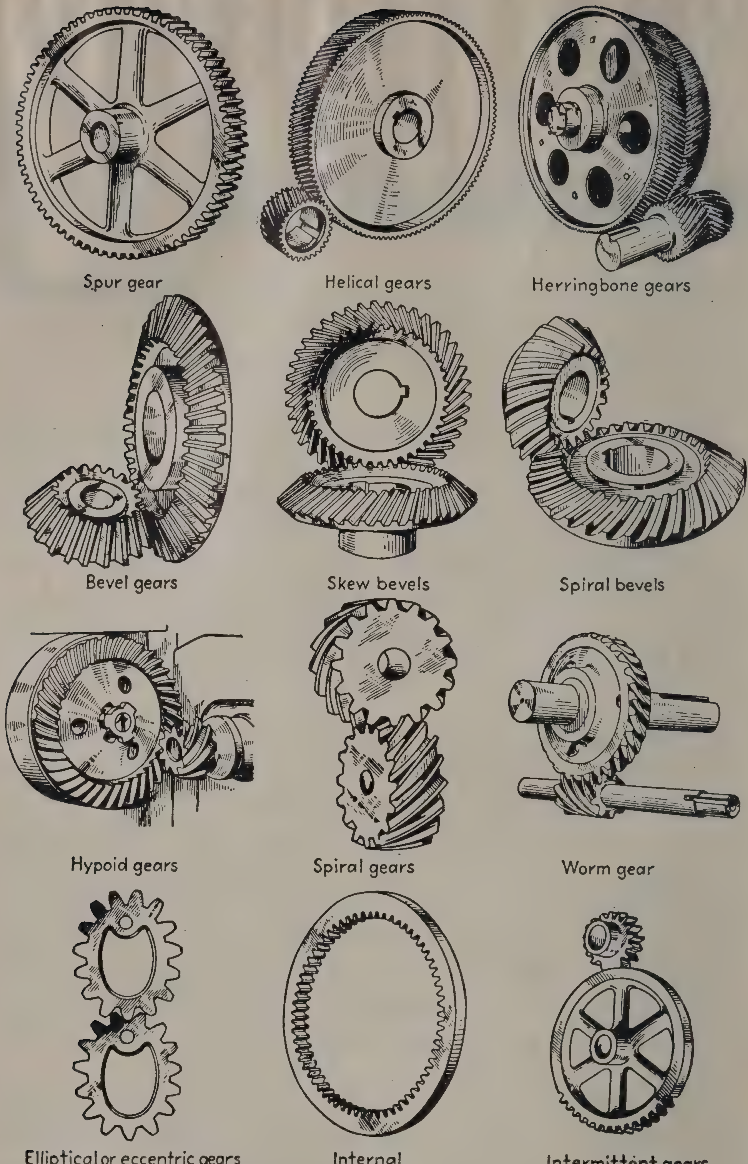


Figure 4–1.—Twelve common types of gears.

GEAR NOMENCLATURE

It is very important that you thoroughly understand the various technical terms used in describing or referring to gear teeth. These terms are defined below, and the names of the gear-tooth parts are shown on the diagram in figure 4–2.

PITCH CIRCLE—an imaginary circle located about one-half the way down on the teeth where the teeth of both gears contact each other.

PITCH DIAMETER—diameter of the pitch circle, or line.

OUTSIDE DIAMETER—the total diameter over the teeth.

CIRCULAR PITCH—the length of the arc of the pitch circle between the center or corresponding points of adjacent teeth.

DIAMETRAL PITCH—the number of teeth to each inch of the pitch diameter or the number of teeth divided by the pitch diameter (diametral pitch is usually referred to simply as PITCH).

CHORDAL PITCH—the distance from center to center of teeth, measured along a straight line.

ADDENDUM—the height of tooth above the pitch circle or the radial distance between the pitch circle and the top of the tooth.

DEDENDUM—the length of the portion of the tooth from the pitch circle to the base of the tooth.

WHOLE DEPTH—the distance from the top of the tooth to the bottom, including the clearance.

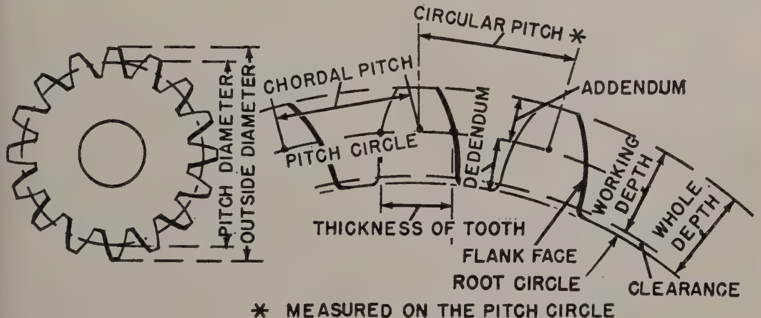


Figure 4–2.—Parts of gear teeth.

Clearance—the extra depth of space between teeth.

Face—the working surface of the tooth above the pitch line.

Flank—the working surface of the tooth below the pitch line.

Thickness—the width of the tooth, taken as the chord of an arc of the pitch circle.

Circular Pitch

The term circular pitch is the distance in inches between the center of one tooth and the center of the next tooth, measured along the arc of the pitch line. There are as many circular pitches (of equal length) in a gear as there are teeth in that gear. It is called linear pitch in racks.

When pitch is used in machine work, it denotes a size. Before the days of form cutters, indexing devices, and gear cutting machines, most gears were cast from patterns and then filed more or less into shape. Circular pitch was then used to designate the size of the gear tooth, and easily measured pitches such as ¼ in., ½ in., ¾ in., etc., were used. When making the pattern, the patternmaker used the circular pitch (or more correctly, he used the chord of the circular pitch or chordal pitch) to space the teeth in the gear; and the calculations for diameter center distance, etc., were based on circular pitch. Today, however, the circular pitch is used only in calculations for gears of coarse pitch, for the reason that for smaller pitches a simpler and better system has been devised.

Diametral Pitch

The diametral pitch system was devised to simplify gear calculations and measurements. It is based on the diameter of the pitch circle, rather than on the circumference. Since the circumference of a circle is 3.1416 times its diameter, this constant always has to be taken into consideration when calculating measurements based on the pitch circumference. In the diametral pitch system, however, the constant is, in a sense, "built into" the system, thus simplifying computation. When using this system there is no need to calculate circular pitch or even chordal pitch. Indexing devices based

on the diametral pitch system will accurately space the teeth, and the formed cutter associated with the indexing device will form the teeth within the necessary accuracy. All calculations, such as center distance between gears, working depth of teeth, etc., are simplified by use of the diametral pitch system.

In the diametral pitch system the pitch diameter is made a convenient dimension, 2 in., 3 in., 4 in., etc. By using this system any number of teeth desired on a gear of given diameter can be made. For example, on one gear of 2 inches in pitch diameter one may cut 20 teeth, and on another gear of the same pitch diameter he may cut 40 teeth. Of course with the 20-tooth gear the teeth will be larger and stronger, while with the 40-tooth gear the teeth will be half the size and will operate with less noise. Remember that two matching gears must be the same diametral pitch before they can mesh. As the diametral pitch gets larger the tooth becomes smaller. (See fig. 4–3.)

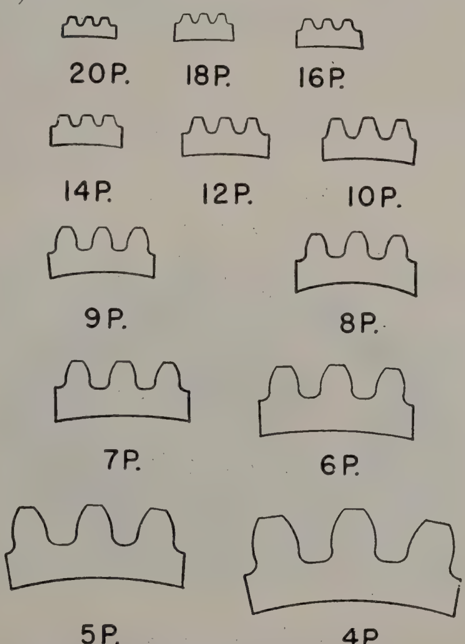


Figure 4–3.—Proportions of teeth of different diametral pitch.

Gear Cutters

Involute formed gear cutters are used to cut the teeth on gears. (See fig. 4–4.) These cutters are made with 8 different forms for each diametral pitch, numbering from 1 to 8. The table below indicates the ranges of the different cutters.

No. of cutter	*Range of teeth*
1	135 to a rack.
2	55 to 134.
3	35 to 54.
4	26 to 34.
5	21 to 25.
6	17 to 20.
7	14 to 16.
8	12 to 13.

It can be seen, if a cutter is wanted for a gear having 40 teeth, a No. 3 cutter would be used, inasmuch as a No. 3 cutter will cut all gears containing 35 to 54 teeth inclusive. Most cutters (see fig. 4–4) are stamped, showing the number of the cutter, the diametral pitch, the range for the number of cutter, and the depth. The involute gear cutters usually (on board a repair ship) run from 1 to 48 diametral pitch, and 8 cutters to each pitch.

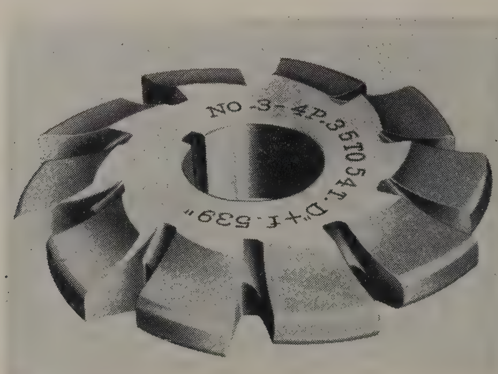


Figure 4–4.—Gear cutter.

Spur gears (see fig. 4–1) may be distinguished by the fact that the teeth are cut squarely across the outer rim of the gear blank in a direction parallel to the gear shaft axis. The standard involute gear tooth (see fig. 4–5) has a pressure angle of 14½°, the pressure angle being the angle at which one tooth bears against the other. This tooth form is the

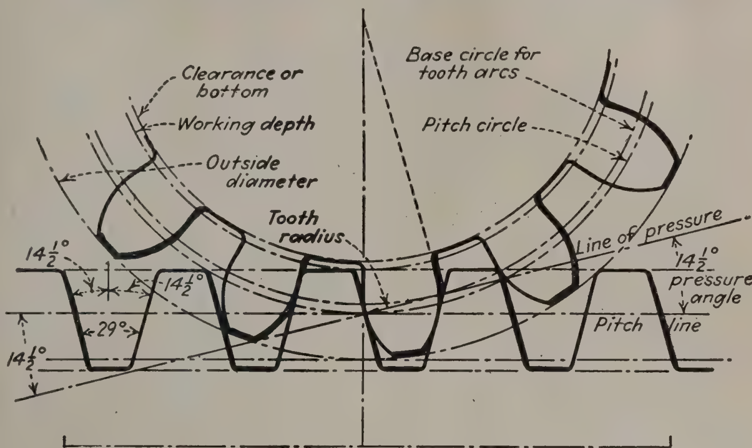


Figure 4–5.—Action of standard 14½° tooth gear and rack.

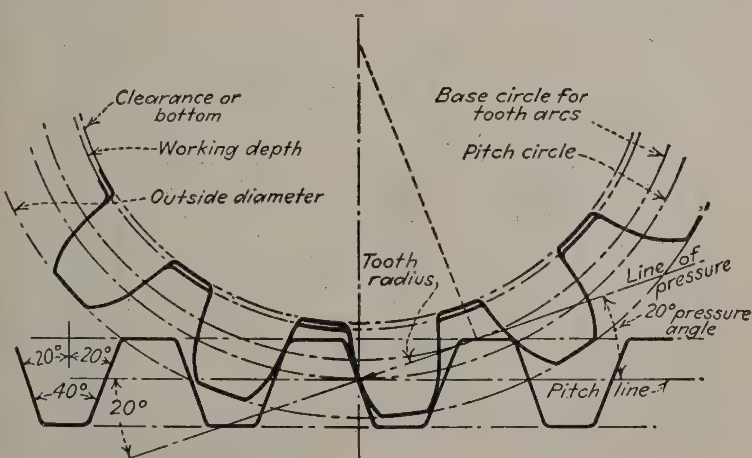


Figure 4–6.—Action of 20° stub tooth gear and rack.

one most commonly used. Another tooth form is the 20° stub tooth (see fig. 4–6). It is much like the standard 14½° spur gear except that it has a pressure angle of 20° and a shorter tooth.

Formulas for Spur Gearing

The formulas on pages 103–106 can be used to figure the dimensions of the various parts of standard spur gears.

Laying Out Spur Gears

When laying out spur gears, remember that 2 divided by the pitch is the working depth of the tooth; that is, 12 pitch teeth are 2/12 in. deep, 8 pitch teeth are 2/8 in. deep, etc.

Assume that the gear is to have 24 teeth and 8 pitch. Draw a circle measuring as many eights of an inch in diameter as there are to be teeth in the gear (see fig. 4–7). This 3-in. circle will be the pitch line. Then with a radius 1/8 in. larger, draw another circle from the same center; this circle will be the outside diameter of the gear.

Thus the outside diameter of an 8 pitch gear of 24 teeth is 26/8 or 3.250 in. Should there be 16 teeth in a small spur gear, as shown in figure 4–7, the outside diameter would be 18/8 or 2.250 in.

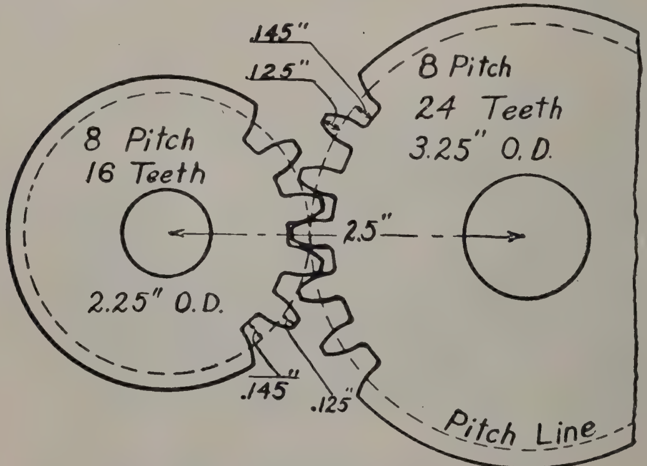


Figure 4–7.—Laying out gears.

Formulas For Spur Gearing

Having	To Get	Rule	Formula
Diametral pitch	Circular pitch	Divide 3.1416 by the diametral pitch	$P' = \frac{3.1416}{P}$
Pitch diameter and number of teeth.	Circular pitch	Divide the pitch diameter by the product of 0.3183 and the number of teeth.	$P' = \frac{D'}{.3183\ N}$
Outside diameter and number of teeth.	Circular pitch	Divide the outside diameter by the product of 0.3183 and the number of teeth plus 2.	$P' = \frac{D}{.3183(N+2)}$
Number of teeth and circular pitch.	Pitch diameter	The continued product of the number of teeth, the circular pitch, and 0.3183.	$D' = NP'\ .3183$
Number of teeth and outside diameter.	Pitch diameter	Divide the product of the number of teeth and the outside diameter by the number of teeth plus 2.	$D' = \frac{ND}{N+2}$
Outside diameter and circular pitch.	Pitch diameter	Subtract from the outside diameter the product of the circular pitch and 0.6366.	$D' = D - (P'.6366)$
Addendum and number of teeth.	Pitch diameter	Multiply the number of teeth by the addendum.	$D' = Ns$
Number of teeth and circular pitch.	Outside diameter	The continued product of the number of teeth plus 2, the circular pitch, and 0.3183.	$D = (N+2)P'.3183$

Formulas For Spur Gearing—Continued

Having	To Get	Rule	Formula
Pitch diameter and circular pitch.	Outside diameter	Add to the pitch diameter the product of the circular pitch and 0.6366.	$D=D'+(P'.6366)$
Number of teeth and addendum.	Outside diameter	Multiply the addendum by the number of teeth plus 2.	$D=s(N+2)$
Pitch diameter and circular pitch.	Number of teeth	Divide the product of the pitch diameter and 3.1416 by the circular pitch.	$N=\frac{D'\ 3.1416}{P'}$
Circular pitch	Thickness of tooth	One half the circular pitch	$t=\frac{P'}{2}$
Circular pitch	Addendum	Multiply the circular pitch by 0.3183; or $\frac{s=D'}{N}$	$s=P'\ .3183$
Circular pitch	Root	Multiply the circular pitch by 0.3683	$s+f=P'\ .3683$
Circular pitch	Working depth	Multiply the circular pitch by 0.6366	$D''=P'\ .6366$
Circular pitch	Whole depth	Multiply the circular pitch by 0.6866	$D''+f=P'\ .6866$
Circular pitch	Clearance	Multiply the circular pitch by 0.05	$f=P'\ .05$
Circular pitch	Diametral pitch	Divide 3.1416 by the circular pitch	$P=\frac{3.1416}{P'}$
Pitch diameter and number of teeth.	Diametral pitch	Divide the number of teeth by the pitch diameter.	$P=\frac{N}{D'}$

Outside diameter and number of teeth.	Diametral pitch	Divide the number of teeth plus 2 by the outside diameter.	$P=\frac{N+2}{D}$
Number of teeth and diametral pitch.	Pitch diameter	Divide the number of teeth by the diametral pitch.	$D'=\frac{N}{P}$
Number of teeth and outside diameter.	Pitch diameter	Divide the product of the outside diameter and the number of teeth by the number of teeth plus 2.	$D'=\frac{DN}{N+2}$
Outside diameter and diametral pitch.	Pitch diameter	Subtract from the outside diameter the quotient of 2 divided by the diametral pitch.	$D'=D-\frac{2}{P}$
Addendum and number of teeth.	Pitch diameter	Multiply the addendum by the number of teeth.	$D'=sN$
Number of teeth and diametral pitch.	Outside diameter	Divide the number of teeth plus 2 by the diametral pitch.	$D=\frac{N+2}{P}$
Pitch diameter and diametral pitch.	Outside diameter	Add to the pitch diameter the quotient of 2 divided by the diametral pitch.	$D=D'+\frac{2}{P}$
Pitch diameter and number of teeth.	Outside diameter	Divide the number of teeth plus 2 by the quotient of the number of teeth divided by pitch diameter.	$D=\frac{N+2}{\frac{N}{D'}}$

Formulas For Spur Gearing—Continued

Having	To Get	Rule	Formula
Number of teeth and addendum.	Outside diameter	Multiply the number of teeth plus 2 by the addendum.	$D=(N+2)s$
Pitch diameter and diametral pitch.	Number of teeth	Multiply the pitch diameter by the diametral pitch.	$N=D'P$
Outside diameter and the diametral pitch.	Number of teeth	Multiply the outside diameter by the diametral pitch and subtract 2.	$N=DP-2$
Diametral pitch	Thickness of tooth	Divide 1.5708 by the diametral pitch	$t=\frac{1.5708}{P}$
Diametral pitch	Addendum	Divide 1 by the diametral pitch or $s=\frac{D'}{N}$.	$s=\frac{1}{P}$
Diametral pitch	Root	Divide 1.157 by the diametral pitch	$s+f=\frac{1.157}{P}$
Diametral pitch	Working depth	Divide 2 by the diametral pitch	$D''=\frac{2}{P}$
Diametral pitch	Whole depth	Divide 2.157 by the diametral pitch	$D''+f=\frac{2.157}{P}$
Diametral pitch	Clearance	Divide 0.157 by the diametral pitch	$f=\frac{.157}{P}$
Thickness of tooth	Clearance	Divide the thickness of tooth at pitch line by 10.	$f=\frac{t}{10}$

The distance from the pitch line to the bottom of the tooth is the same as the distance from the pitch line to the top, excepting the clearance. The clearance is usually $\frac{1}{10}$ the thickness of the tooth at the pitch line, and it is provided for in the shape of the formed cutter.

Cutting a Spur Gear

To set up the milling machine with a formed cutter for cutting a spur gear, you should proceed as follows:

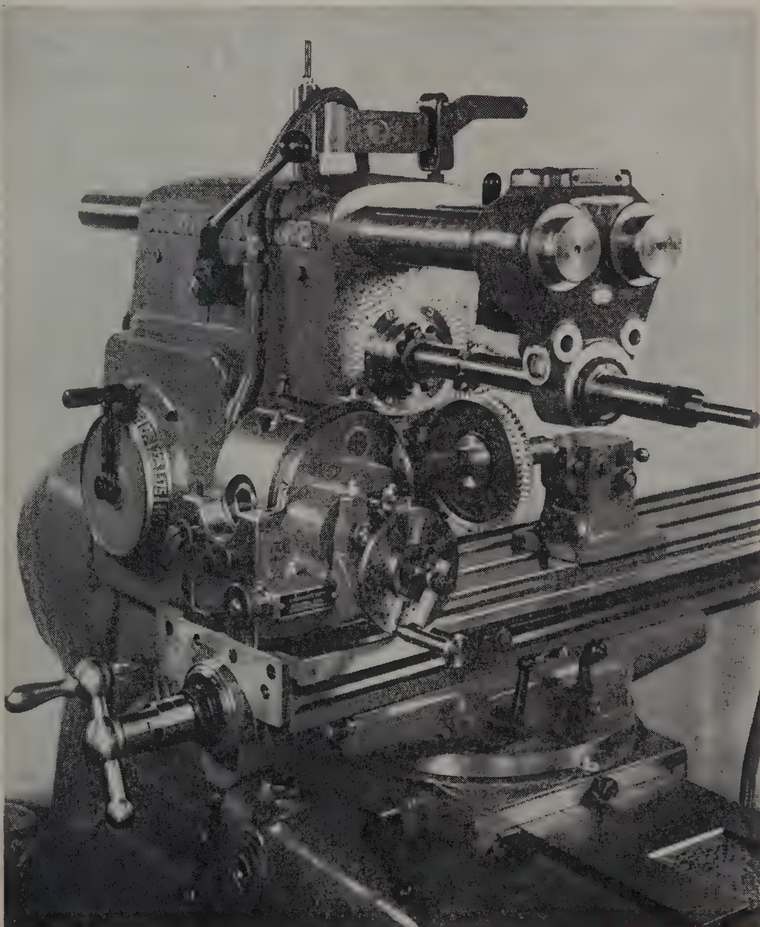


Figure 4–8.—Cutting a spur gear.

Fasten the index centers to the milling machine table and align them if necessary. When using the universal milling machine, set the table at right angles to the cutter arbor so that the tooth space cut will be parallel to the axis of the gear. (See fig. 4–8.)

Secure the gear blank to the mandrel. At this point, be sure to see that the mandrel runs true so that all teeth cut upon the blank have the same relationship to the axis.

Adjust the cutter centrally with the axis of the gear blank. To make this adjustment (1) set a surface gage to the same height as the centers and inscribe a horizontal line across the peripheral surface of the gear blank; (2) index the blank 10 turns or one-fourth of a revolution to bring the inscribed line to top-center; (3) adjust the table to a position which places the line directly under and in the center of the cutter; (4) with the cutter revolving, raise the gear blank until tool marks are left on its periphery, and then stop the cutter and lower the blank sufficiently to examine the tool mark and inscribed line; (5) if necessary, move the table transversely to bring the line directly under the center of the cutter.

A less accurate method of making this adjustment is a visual alignment of either the headstock or tailstock center with the center of the cutter.

Regulate the depth of cut by adjusting the height of the milling machine knee. With the cutter revolving, raise the knee until the cutter just touches the blank. Then lock the graduated dial on the vertical feed and use this dial as a guide in determining the required tooth space depth. Move the blank from under the cutter by turning the longitudinal feed and set the depth of the cut by raising the vertical feed the required number of thousands of an inch.

Before taking a cut through the blank it is a good practice to make a trial cut by nicking the blank all around its circumference; then if any error has been made in setting the dividing head it can be corrected before the gear blank has been damaged.

An error will be indicated if the cutter does not line up with the first nick. Another method is to nick the blank for

the first tooth and then index for the proper number of teeth. If on the last index the cutter lines up with the nick, cutting of teeth can be started.

If gear teeth are fairly coarse pitch it may be desirable to take roughing and finishing cuts. This is often done in cutting gears coarser than 6 or 7 diametral pitch, although a definite dividing line cannot be drawn, owing to variations in both the cutting capacity of the machine itself and the cutting qualities of the stock.

If the outside diameter of the gear blank is correct, the tooth thickness should also be correct after the cutter has been sunk to the depth required for a given pitch. However, it is advisable to check the size of the tooth by measuring it with a gear-tooth vernier caliper.

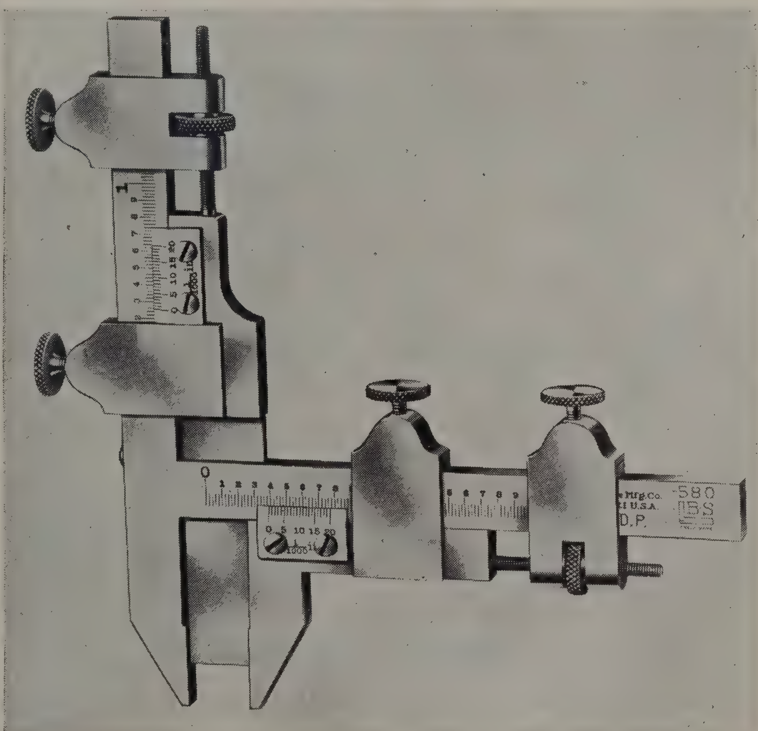


Figure 4–9.—Measuring gear teeth with a vernier caliper.

To check the thickness of the tooth, it is necessary to cut two tooth spaces into the face of the gear blank to a predetermined depth to produce the full form of the tooth. The vertical slide of the gear tooth caliper is set so that when it rests upon the top of the tooth, as shown in figure 4–9, the lower ends of the caliper jaws will be at the height of the pitch circle. The horizontal scale shows the chordal thickness of the tooth at this point. If the tooth is too thick, it will be necessary to raise the work into the cutter; if the tooth is too narrow, the work must be lowered.

For a more accurate check on gear teeth, it is necessary to work to chordal thickness and the corrected addendum. The formulas to be used in determining the chordal thickness and corrected addendum can be found in various machinists' handbooks.

Milling Rack Teeth

A rack may be compared to a spur gear that has been straightened out and fastened to a milling machine bed. The pitch of the rack teeth, or the center-to-center distance between adjacent teeth, must equal the circular pitch of the mating gear.

A No. 1 spur gear cutter of the required diametral pitch is used to cut rack teeth, since this number is intended for spur gears varying from 135 teeth to a rack. The depth of the tooth is calculated in the same manner as is the depth of a spur gear tooth.

For milling rack teeth, a special rack-cutting attachment is usually used. (See fig. 4–10.) This attachment holds the cutter at 90° to the length of the table. The teeth are indexed by using the longitudinal feed dial. Set the dial at zero for the first tooth and feed the rack into the cutter with the cross-feed screw.

Cutting Internal Spur Gears

Internal gears may be considered as circular metal bands having teeth on their inside surfaces (see fig. 4–1). These gears are proportioned like a standard spur gear turned

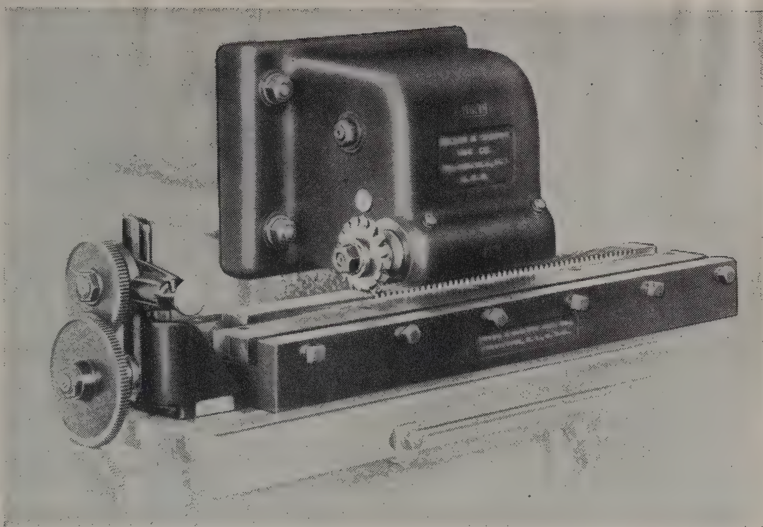


Figure 4–10.—Cutting teeth in a rack, using a rack milling attachment.

"outside in," or with dedendum and addendum in reverse positions. The rules for finding the dimensions of an internal spur gear, then, are similar in most cases to those for external spur gearing.

Internal spur gears are cut by methods similar to those employed for external spur gears. Aboard ship they are usually cut by planing with a formed tool which reproduces its shape, the planing action being produced either by slotting or a planing type of machine.

STUB TOOTH GEARS

Stub involute tooth gears are largely used in automotive drives because of their strength. This type of gear tooth has a 20° pressure angle and is short and thick, as the name implies. The stub gear tooth is shown in figure 4–5, the standard involute form in figure 4–6. Three systems of stub tooth gearing are in general use; they are the Nuttall, the Fellows, and the American Standards Association.

The Nuttall system of stub tooth gearing bases the tooth dimensions directly upon the circular pitch, the addendum

being made $\frac{1}{4}$ of the circular pitch, and the dedendum $\frac{3}{10}$ of the circular pitch.

The American Standards Association bases the tooth dimensions upon a given set of formulas; the total depth of tooth is 1.8 divided by the diametral pitch; the addendum, 0.8 divided by the diametral pitch; and the basic thickness of the tooth, 1.5708 divided by the diametral pitch.

The Fellows system of stub tooth gearing bases the tooth dimensions on two diametral pitches. For example, the gear tooth may be designated as a $\frac{10}{12}$ pitch; the numerator of this fraction is the pitch that determines the thickness and number of teeth, and the denominator is the pitch that determines the depth of the teeth. The following formulas are used in calculating dimensions for the Fellows system of stub tooth gearing:

The pitch diameter (D') is determined by dividing the number of teeth (N) by the numerator pitch:

$$D' = \frac{N}{\text{numerator pitch}}$$

The addendum (s) is determined by dividing the number one by the denominator pitch:

$$s = \frac{1}{\text{denominator pitch}}$$

The outside diameter (D) of the gear blank equals the sum of the pitch diameter (D') and two times the quotient of 1 divided by the denominator pitch:

$$D = D' + \left(2 \times \frac{1}{\text{denominator pitch}}\right)$$

The dedendum is determined by dividing the number 1 by the denominator pitch:

$$\text{Dedendum} = \frac{1}{\text{denominator pitch}}$$

The tooth clearance (f) is determined by dividing the addendum (s) by the number 4:

$$f = \frac{s}{4}$$

After the stub tooth calculations have been made according to one of the above systems, the proper stub tooth cutter should be selected according to the diametral pitch. The milling operation for cutting stub tooth gears is the same as for milling standard involute teeth.

BEVEL GEARS

Bevel gears have teeth cut on an angular face for transmitting motion between shafts that are set at an angle to each other (see fig. 4–1). When the gears have the same number of teeth and their shafts are at right angles they are usually referred to as miter gears.

Straight-tooth bevel gears may be cut by using a form cutter or by means of a generating process. In the generating process the teeth are planed or shaped by a tool traveling across the face of the gear blank, which rolls so as to produce

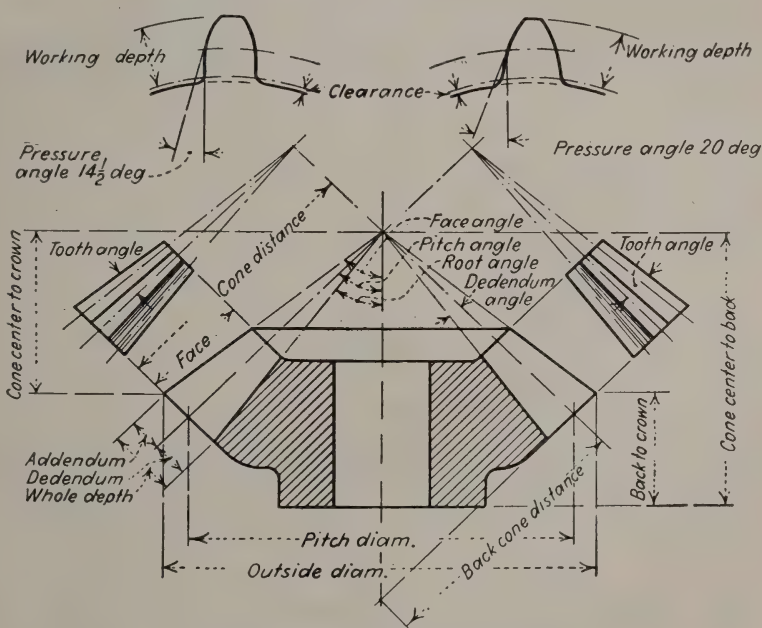


Figure 4–11.—Parts of a bevel gear.

the proper form of tooth. Since the teeth of bevel gears constantly change in pitch from their large end to their small end, form rotary cutters do not produce as accurate a bevel gear as the planing method, but they do produce gears of sufficient accuracy to meet repair needs aboard ship.

Parts of Bevel Gears

In addition to the gear nomenclature you have already learned, you will need to learn a few more terms which apply to bevel gears. The names of the parts of a bevel gear are shown in figure 4–11.

Data Required for Cutting Bevel Gears

In order to cut a bevel gear you must know (1) the pitch and number of teeth in each gear, (2) the whole depth of tooth spaced at both large and small ends of the teeth, (3) the thickness of the teeth at both ends, (4) the height of the teeth above the pitch line at both ends, (5) the cutting angle, and (6) the angle at which to set the headstock on the milling machine.

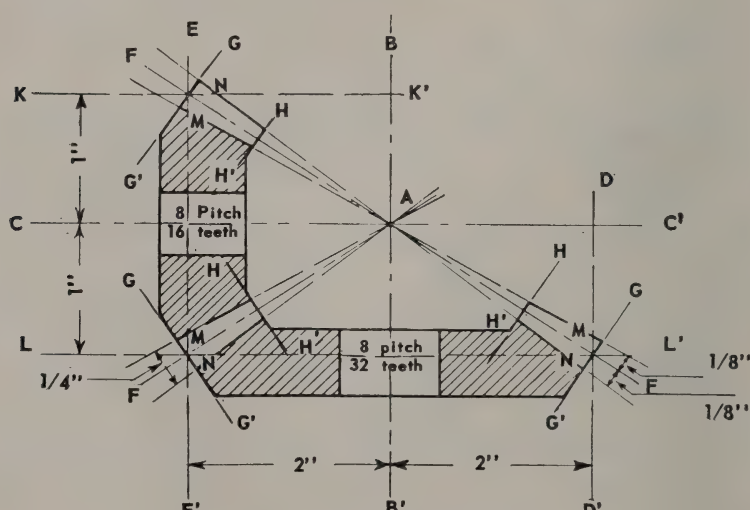


Figure 4–12.—Laying out bevel gears.

Laying Out Bevel Gears

Laying out a bevel gear is somewhat more complicated than laying out a spur gear. The following example shows you how to lay out gears which are to be 8 pitch, with one gear having 32 teeth and the mating gear 16 teeth, and with the shaft intersection at 90°.

Draw the center lines BB′ and CC′ intersecting at right angles at center point A, as shown in figure 4–12. Then draw the vertical lines DD′ and EE′ the same distance each side of BB′ and parallel to it, the distance between DD′ and EE′ being as many eighths of an inch (teeth being 8 pitch) as there are to be teeth in the gear. Since there are to be 32 teeth in the gear, the distance between lines DD′ and EE′ (the pitch diameter) will be $^{32}/_{8}$, or 4 inches, or the lines will be 2 inches each side of line BB′. Horizontal lines KK′ and LL′ are similarly drawn with respect to center line CC′. Since there are to be 16 teeth in the smaller gear, the distance between lines KK′ and LL′ (the pitch diameter) will be $^{16}/_{8}$, or 2 inches, or the lines will be 1 inch each side of line CC′.

Then draw three lines from the intersection points of lines EE′ and LL′, DD′ and LL′, and EE′ and KK′ to the center point A, and label them FA. These lines are called the pitch lines. Through the same three points of intersection of the above lines, draw lines at right angles to the pitch lines. These three lines are labeled GG′; they form the material conical surfaces of the back of the gear teeth. On the GG′ lines, lay off points M and N ⅛ in. (teeth being 8 pitch) each side of the pitch lines, and draw the six lines MA and NA, forming the faces and bottoms of the teeth. Then draw the three lines HH′ parallel to the lines labeled GG′. The distance between the lines HH′ and GG′ is the width of the gear face. (The width of the gear face is made ⅓ of the pitch cone radius for gears up to 3 in. in pitch diameter, and ¼ of the pitch cone radius for gears having 3 to 20 in. of pitch diameter.)

The face of the larger gear should be turned to the line MA, and the face of the smaller gear to NA.

Selecting the Cutter

Special cutters are made for cutting bevel gears. These cutters are similar in appearance and size to those used for cutting spur gears, but are made with thinner teeth. Like spur gear cutters, bevel gear cutters are made in eight different forms for each pitch. The selection of the proper cutter is determined not by the actual number of teeth in the gear, but by a hypothetical number of teeth. This hypothetical number is determined by multiplying the back cone radius by 2, and multiplying this product by the diametral pitch.

To determine the back cone radius, draw to scale a cross-sectional view of the bevel gear and pinion to be cut, as shown in figure 4–13, making lines AB and BC at right angles to line PB and extending them to intersect the center lines of the gears. The distance AB is the back cone radius of the gear, and BC is the back cone radius of the pinion.

As an example of the above calculation, assume that it is required to select the proper cutter for an 8 pitch bevel gear and pinion having 32 teeth on the gear, 16 teeth on the pinion, a back cone radius of 5 in. (by measurement) for the gear,

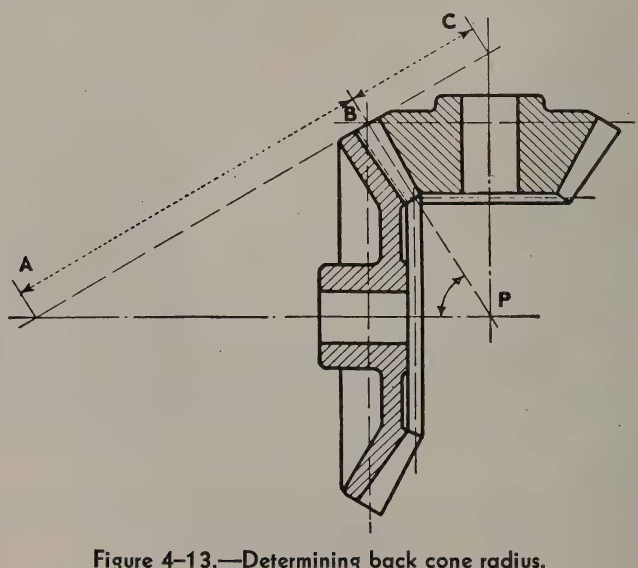


Figure 4–13.—Determining back cone radius.

and a back cone radius of $1\frac{1}{8}$ in. (by measurement) for the pinion.

Multiplying $5 \times 2 \times 8$ we find that the hypothetical number of teeth for the gear is 80; therefore, the proper cutter is No. 2. (See the table on page 100.) Multiplying $1\frac{1}{8} \times 2 \times 8$, we find that the hypothetical number of teeth for the pinion is 18; therefore, the proper cutter is No. 6.

Setting the Cutter Out of Center

Since the thickness of the cutter is selected for the width of the tooth space at the small end of the tooth, it is necessary to set the cutter out of center with the blank and rotate the blank in order to cut the spaces to the correct width at the large end of the tooth (see fig. 4–14). The factors given in the table on page 118 are used to determine the amount of set-over for the work table.

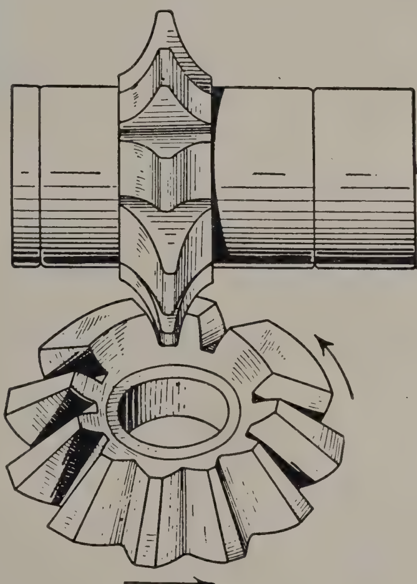


Figure 4–14.—Offset and rotation of work in bevel gear cutting.

Number of cutter	Ratio of pitch cone radius to length of face												
	$\frac{3}{1}$	$\frac{3\frac{1}{4}}{1}$	$\frac{3\frac{1}{2}}{1}$	$\frac{3\frac{3}{4}}{1}$	$\frac{4}{1}$	$\frac{4\frac{1}{4}}{1}$	$\frac{4\frac{1}{2}}{1}$	$\frac{4\frac{3}{4}}{1}$	$\frac{5}{1}$	$\frac{5\frac{1}{2}}{1}$	$\frac{6}{1}$	$\frac{7}{1}$	$\frac{8}{1}$
	Set-over factor (inches)												
1	0.254	0.254	0.255	0.256	0.257	0.257	0.257	0.258	0.258	0.259	0.260	0.262	0.264
2	.266	.268	.271	.272	.273	.274	.274	.275	.277	.279	.280	.283	.284
3	.266	.268	.271	.273	.275	.278	.280	.282	.283	.286	.287	.290	.292
4	.275	.280	.285	.287	.291	.293	.296	.298	.298	.302	.305	.308	.311
5	.280	.285	.290	.293	.295	.296	.298	.300	.302	.307	.309	.313	.315
6	.311	.318	.323	.328	.330	.334	.337	.340	.343	.348	.352	.356	.362
7	.289	.298	.308	.316	.324	.329	.334	.338	.343	.350	.360	.370	.376
8	.275	.286	.296	.309	.319	.331	.338	.344	.352	.361	.368	.380	.386

In making use of these offset values, the ratio of the pitch cone radius to the length of face must first be found; this is done by dividing the pitch cone radius by the width of the face. That ratio given in the horizontal scale of the table which most nearly approaches the ratio calculated is the offset factor required. This factor may then be substituted in the following formula to give the correct amount to offset the work table:

$$\text{Table offset} = \frac{Tc}{2} - \frac{\text{set-over factor}}{P}$$

WHERE

P=diametral pitch of gear to be cut, and

Tc=thickness of cutter, measured at the pitch line.

The thickness of the cutter, measured at the pitch line, should be determined for the cutter being used, because regrinding may have caused slight variations from the recorded thickness of the cutter. The thickness may be measured with the gear tooth vernier caliper, the vertical slide being set to measure the cutter at the pitch line. The required setting is determined by dividing 1.157 by the diametral pitch (P).

$$\text{Vernier caliper setting} = \frac{1.157}{P}$$

As an example of the above calculation, assume that it is necessary to determine the amount of offset required to cut the bevel gear in figure 4–10. This gear has a pitch cone radius of 2.309 in. and a face width of 0.770 in. By referring to the cutter calculations previously given, you will see that a No. 2 cutter should be selected. The ratio of the pitch cone radius to the length of face is

$$\frac{2.309}{0.770} = \frac{3}{1}$$

According to the table the factor most nearly corresponding to the above ratio is found to be 0.266 in. The thickness at the pitch circle of the No. 2, 8 pitch, cutter is 0.1644 in. Substituting these values in the formula, the amount of offset is found to be 0.048.

$$\frac{0.1644 \text{ in.}}{2} - \frac{0.266 \text{ in.}}{8} = 0.048$$

As previously mentioned, it is necessary to rotate the gear blank when trimming the sides of the teeth. First cut two adjacent tooth spaces in the gear blank with the cutter set centrally. Then set the cutter off center the required amount, as calculated, by moving the milling machine table transversely, gaging the amount of movement by the graduated dial on the transverse feed. By indexing, rotate the gear in an opposite direction from that in which the table is moved off center, allowing the side of the cutter nearest the center line of the gear to cut the entire surface of the approaching side of the tooth. Then move the work away from the cutter, offset the table the proper distance on the opposite side of center, and repeat the operations of rotating and cutting the tooth.

The gear tooth so trimmed should be measured at the large end by using the gear tooth vernier caliper. Correction may then be made on the basis of the vernier reading. Remember that a cutter set too much out of center leaves the small end of the tooth too thick, and one that is not offset enough leaves the small end too thin. It is better to have a slight variation in depth than an incorrect thickness of teeth.

WORM GEARING

Worm gearing is used when a large reduction in velocity is desired or when considerable increase in mechanical advantage is required. As shown in figure 4–1, a worm gear set combines a screw or worm with a worm wheel which has helical teeth and is mounted on a shaft usually at right angles to that of the worm. The worm is generally machined (including the cutting of the screw thread) on the lathe; the worm wheel blank is turned on the lathe, and the teeth are cut on the milling machine.

Cutting Worm Wheels

There are various ways of producing a worm wheel on a milling machine. The most commonly used method con-

sists of two operations: First, gashes are milled around the worm-gear blank to form the teeth roughly; then the teeth are hobbed.

For gashing the teeth the blank is dogged to the headstock spindle and the swivel table is swung to the required angle. (See fig. 4–15.) Gashing is done preferably with an involute spur gear cutter of a number and pitch corresponding to the number and pitch of the teeth in the worm wheel. The

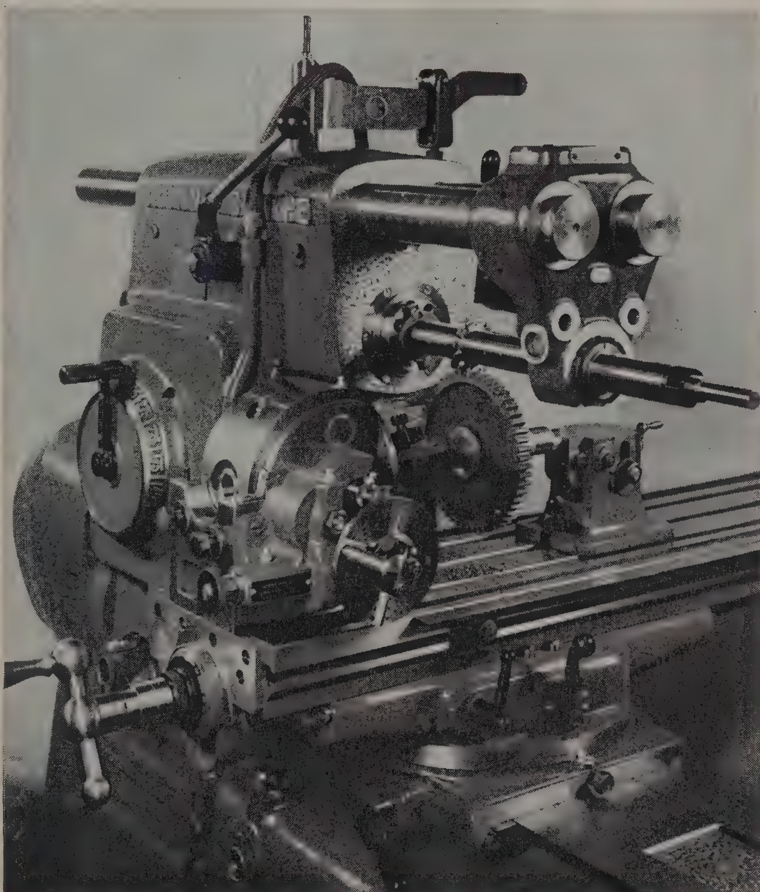


Figure 4–15.—Gashing worm-wheel teeth.

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vertical feed is used and the teeth are indexed in the same manner as in cutting a spur gear. Most of the stock is removed in gashing, only enough being left to allow the hob to take a light finishing cut.

The work is then set up in practically the same manner as for the gashing operation, except that the dog on the arbor is removed and the swivel table is set at zero. (See fig. 4–16.)

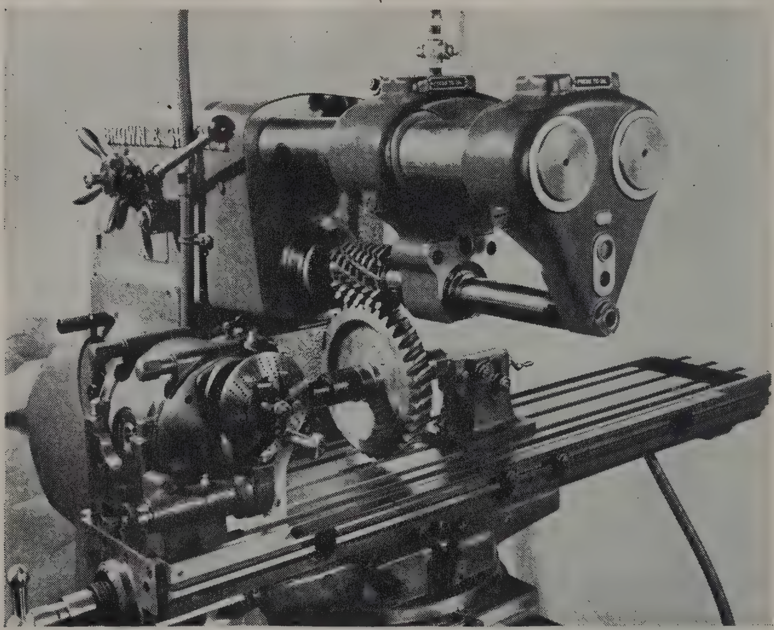

Figure 4–16.—Milling machine set for hobbing worm wheel.

The gashing cutter is replaced with a hob which will mesh with the gashes in the blank. As the hob is revolved, the worm wheel revolves with it. At the same time, the gear blank is gradually elevated so that teeth which mesh accurately with those of the hob are formed on it. Since the hob is a duplicate of the worm, except for provisions necessary to convert it into a cutting tool, it is evident that the worm wheel produced in this manner will mesh with the worm. The clearance between the worm and worm wheel

is obtained by making the outside diameter and the root diameter of the hob slightly greater than corresponding dimensions of the worm.

Worm Threads

Worms, particularly single- and double-thread, are usually cut with threads having a 29° included angle. The threads are either cut by a lathe using a single-point tool or they are milled by a milling machine.

As you know, a single-lead worm turns the worm wheel one tooth for each revolution of the worm; a double thread, or start, worm moves the worm wheel two teeth per revolution; and so on. As the number of starts increases, with the same diameter of worm, the helix angle may become very sharp, often exceeding 45°. On account of tool clearance, worms with large helix angles are usually made by the milling machine, since an increased helix angle adds to the difficulty of cutting the thread.

When cutting worms with multiple-lead threads, remember that the thread depth and other dimensions should be divided by the number of leads. For example, a triple-lead screw of 1-in. pitch will be only ⅓ as deep and ⅓ as wide as if it were a single lead.

HELICAL GEARS

Helical gears, often incorrectly referred to as spiral or skew gears, have teeth cut across the outer rim of the gear blank at an angle to their axis similar to the thread of a screw. (See fig. 4–1.) Most helical gears are made with a tooth angle of 45°, this angle providing the most efficient and most durable gear, although any angle which permits the teeth to engage properly may be used.

Usually when you are required to cut a pair of helical gears, you will be furnished either with a sample pair of gears (the worn-out gears which are being replaced) or with drawings of the gears. From these you can usually obtain sufficient information to cut satisfactory gears. If you need

further information to calculate dimensions, you will find the necessary formulas and tables in various machinists' handbooks.

Although most helical gears are cut on a gear cutting machine, aboard ship they will be cut on the universal milling machine or on the standard milling machine, using the vertical spindle attachment. To space the teeth equally around the gear blank, the dividing head and footstock are used. The milling machine must be geared to the proper lead and the table set to the proper helix angle.

When cutting helical gears, it is important to remember that the helix angle is dependent upon the design of the gears and the relative position of the shafts. For example, when the shaft axes are parallel, the teeth must have opposite helix angles so that they may mesh; but when the shaft axes are at right angles, the teeth must have the same helix angle.

MATERIALS USED FOR GEARS

Gears are made from many materials. Cast iron may be used. Steel is used whenever great strength and toughness are required. The various classes of steel have different properties and must be used with their relative advantages and disadvantages in mind. Nonferrous metals such as bronze and brass are often used aboard naval vessels for gears which must be resistant to salt-water corrosion. Monel metal and aluminum may be used for some purposes. Nonmetallic gearing is frequently used where quietness of operation is important. Nonmetallic gears are most effective when used for high-speed duty; they do not always hold up properly against the wide fluctuations of load and the high shock loads which may be encountered at low speeds. Although gears made of nonmetallic materials have a lower tensile strength, their greater resiliency gives them approximately the same power-transmitting capacity as cast iron.

The choice of material for a particular gear will be deter-

mined on the basis of the function of the gear; specifically, this will involve such factors as the speed of operation, the type of stress to be encountered, the importance of quiet operation, and the need for resistance to corrosion. Generally you will know what material to use by finding out what material was used in the gear for which you are making a replacement. Perhaps you will have the original gear itself to go by; or perhaps you will be able to find specifications or blueprints for the original gear. In some instances you may want to consult the machinists' handbooks, which describe the various materials, in order to make sure that the material you are using will actually hold up under the particular stresses which the gear will have to take.

CUTTING FLUIDS

In cutting gears, you will find that it is sometimes better to cut them dry, and sometimes better to use a cooling or lubricating fluid. Which method to use depends on the nature of the material being cut, and the amount or type of finish required. In general, the functions of cutting fluids are to keep the tool and the work from being damaged by excessive localized heating; to wash away chips; to protect the machined surfaces against corrosion; and in some cases to improve the surface finish. Sometimes the fluid will be chosen to perform only one of these functions; but in some instances you may have to find a cutting fluid which will do all these things. Basically, the choice is between fluids which are COOLING (water containing some alkali, or a water-and-oil emulsion) and those which are LUBRICATING (mineral oil or lard oil combinations). These fluids, and their various possible combinations and proportions, are discussed in considerable detail in most machinists' handbooks. Also, instructions furnished by the manufacturer frequently indicate which cutting fluid should be used with a particular machine.

BACKLASH

A certain amount of backlash, or play between the meshing teeth, is often specified in a pair of mating gears. This is obtained by cutting the teeth thinner or by reducing the pitch diameter of the gear. Usually the teeth of both mating gears are cut thinner to the extent of one-half of the total backlash desired. Sometimes, however, depending upon the type and the relative sizes of the gears, all of the backlash may be obtained on one gear and the other one may be made to standard size. Machinists' handbooks will give you various tables showing average backlash for general purpose gearing, how to provide for a desired amount of backlash, and methods of measuring backlash.

REPAIR SHIP EQUIPMENT FOR GEAR CUTTING

Aboard ship the milling machine is almost always used for gear cutting. Some repair ships or repair bases may have gear hobbing machines or gear generators, but setting up these machines is so complicated that their use is practical only when a large number of gears of the same pitch are to be produced, or when extreme accuracy is required. It should be emphasized that gear cutting aboard ship is likely to be a matter of repair rather than of production. Gears are usually carried as spare parts; so, although you will be called upon to cut them for emergency repair jobs, this will not be a routine part of your work. The actual production of gears is best accomplished by civilian manufacturers who have the facilities for fine tolerance work and for mass production.

QUIZ

1. In Navy machine shops, what machine is most often used for gear cutting?
2. What are the four types of gears that are ordinarily cut in a machine shop?
3. What is meant by the term circular pitch?
4. What is chordal pitch?

5. What term is used to describe the imaginary circle located about one-half way down on the teeth where the teeth of both gears make contact with each other?
6. Why is the diametral pitch system used whenever possible in preference to the circular pitch system?
7. What term describes the angle at which one tooth bears against the other?
8. What is the most commonly used tooth form for spur gears? What is its pressure angle?
9. How can you make certain that the dividing head has been properly set, before actually taking a cut through the gear blank?
10. The pitch of rack teeth must be equal to what measure of the mating gear?
11. Aboard ship, what method is generally used for cutting internal spur gears?
12. What characteristic of stub tooth gears makes them more useful than standard spur gears for automotive drives?
13. What term is used to refer to bevel gears which have the same number of teeth and have their shafts at right angles to each other?
14. The proper cutter for bevel gears is determined not by the actual number of teeth per gear, but by a hypothetical number of teeth. How is this hypothetical number determined?
15. For bevel gears, in which measurement is accuracy most important: depth of tooth, or thickness of tooth?
16. What type of gearing would be most likely to be used to achieve a large reduction in velocity or a considerable increase in mechanical advantage?
17. What two operations are involved in the method most commonly used to produce worm gears on a milling machine?
18. What factors determine the helix angle of helical gears?
19. What is the most important thing to consider when selecting the material for a gear?
20. What are the two main reasons for using cutting fluids?
21. What term is used to describe the play between the meshing teeth of gears?

CHAPTER 5

GRINDING WORK

In the past few years a far greater advance has been made in the design, construction, and use of the grinding machine than in any other machine tool. This machine is now recognized as one of the most important machine tools by both industry and the Navy.

Grinding machines in use in the Navy are surface grinders, cutter and tool grinders, and cylindrical grinders. Surface grinding machines are used for all kinds of flat work that may be finished either by the edge or by the face of a grinding wheel. Cutter grinders are used in sizing reamers, cutters, end mills and similar tools, and in maintaining these tools in good working condition. Cylindrical grinders may be of the common-center or of the centerless type, and are used for grinding spindles, shafts, and cylinders.

Possibly because of its comparatively rapid development, grinding is the operation least understood by the otherwise well-trained Machinery Repairman. This chapter is designed to give you a general picture of grinding machines, the grinding wheels used with them, and the methods of operation. It is recommended, however, that you procure and study the manufacturers' manual for the specific type of machine on which you, or lower-rated men under your supervision, will work.

GRINDING WHEELS

In any grinding operation, the selection of the proper grinding wheel is of first importance. The factors to be con-

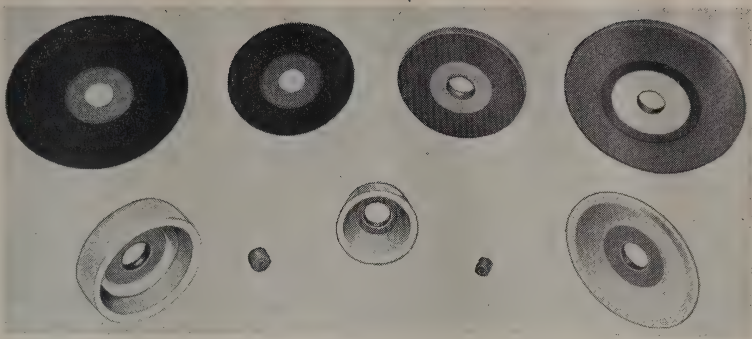

Figure 5–1.—Types of grinding wheels.

sidered are (1) the abrasive from which the wheel is formed—and this includes grain and grade, (2) the wheel structure, (3) the bonding material, (4) the nature of the material to be ground, (5) the amount of material to be removed, and (6) the accuracy and the quality of the finish required. Manufacturers' markings on grinding wheels will help you to determine the first three factors.

Some typical grinding wheels are illustrated in figure 5–1. Wheels No. 6 and No. 8, in the foreground of the illustration, are used for internal grinding. The wheels shown here are typical wheels required for sharpening a wide variety of cutters and performing other toolroom work.

Abrasives

The most common abrasives are aluminum oxide and silicon carbide. Aluminum oxide crystals, though not particularly hard, are tough and hence are usually preferred for grinding materials of high tensile strength such as alloy and high-speed steels. This abrasive is known by such trade names as Aloxite, Alundum, Borolon, and others.

Silicon carbide crystals are very hard but quite brittle; hence wheels of this material are used in grinding easily penetrated materials (such as copper, rubber, and celluloid), and hard materials of low tensile strength (such as cast iron and cast bronze). This abrasive is known by the trade names Carborundum, Crystolon, Electrolon, and others.

An important consideration in the selection of grinding wheels is the nature of the material to be ground. Surface speeds of wheel and work, amount of material to be removed, and accuracy and quality of finish desired are also to be considered.

Grain

The term grain refers to the size of the particles of abrasive used in the wheel. A 46-grain wheel, for example, is made of abrasive that will just pass through a screen having 46 meshes or openings per linear inch.

Several sizes of abrasives are often combined to produce a wheel of special characteristics. Such a wheel is called a combination wheel.

For rough grinding, when the finish is not important, coarse-grain wheels are used. When the finish is more important, or when the surface to be ground is narrow and requires a sharp edge, fine-grain wheels are used. Wheels as fine as 500 grain may be used to meet special requirements.

Grade

Wheels from which the grit is readily torn are known as soft bond or soft grade wheels, while those that strongly retain the grit are called hard bond or hard grade. The term grade refers to the breakdown resistance of the wheel and not to the hardness of the abrasive. In general, hard grade wheels are used in grinding soft steel and similar metals and soft grade wheels are used on the very hard metals. The greater the contact between work and wheel the softer the grade should be.

Wheel Structure

The term wheel structure refers to the spacing between the abrasive particles in the wheel. Since the chips produced from soft, ductile materials will be relatively large, a wheel of open structure is needed in order to give enough chip space to prevent the wheel from becoming loaded;

while hard, brittle materials, yielding smaller chips, are ground most efficiently with a wheel of denser structure. In most cases a wheel of medium structure will be satisfactory, although in some cases a change in structure may often result in better grinding and longer wheel life.

Bonds

Differences in bond give the grinding wheels varied characteristics. Vitrified clay is the bond most commonly used. Wheels of this type are usually preferred for general toolroom work and cutter grinding, for they are unaffected by heat, cold, water, and oils. They are usually not as strong as wheels of other bonds, however, and have practically no elasticity; consequently it is not advisable to attempt a heavy side cut with wheels of this type.

Silicate or semivitrified wheels (bonded with sodium silicate) as a rule cut smoothly and with little heat, hence are suitable for work requiring a delicate edge such as cutter or tool grinding.

Shellac forms a strong bond, and very thin wheels made of it are safe. These wheels produce a smooth finish and deep side cuts can be taken.

Rubber forms a bond of great strength, and wheels bonded with this material are used to cut grooves and for similar work.

Wheels bonded with sodium silicate, shellac, or rubber are not recommended for general cutter grinding.

Standard Markings

Grinding wheels are given standard markings by their manufacturers; these markings consist of a sequence of symbols which indicate the most important characteristics of a grinding wheel. On wheels that are too small for complete marking, only the symbols for grain and grade may appear, or a wheel may come accompanied by a tag or label showing the complete markings.

These standard markings apply also to abrasives such as

bricks, sticks, bones, rubs, and segments used to remove material, to alter shape or size, to produce surface or accuracy of dimensions, or to perform any combination of these processes. These standards, however, do NOT apply to diamond or special wheels, or to sharpening stones.

The sequence of standard markings consists of six positions, arranged as follows:

C 46 M 10 E 26

Position

1. Abrasive type
2. Grain Size
3. Grade
4. Structure
5. Bond Type
6. Manufacturer's Record

1. Abrasive Letters.—The letter C is used for silicon carbide and the letter A is used for aluminum oxide. Some manufacturer may designate some particular type in either of these broad classes.
2. Grain Size.—The grain size is indicated by a number, from coarse to very fine: 10, 12, 14, 16, 20, 24, 30, 36, 46, 54, 60, 70, 80, 90, 100, 120, 150, 180, 220. The following sizes are used occasionally: 240, 280, 320, 400, 500, 600. The manufacturer may add number and additional symbol to indicate a special grain combination.
3. Grade.—The grade is indicated by a letter of the alphabet, A to Z, soft to hard, in all bonds or processes.
4. Structure.—The use of a structure symbol is optional. The structure is indicated by numbers from 1 to 15 (or higher if necessary), the progressively high numbers indicating less density and a wider grain spacing.
5. Bond or Process.—Bonds are indicated by the following letters: V, vitrified; E, shellac or elastic; S, silicate; R, rubber; B, resinoid; O, oxychloride.
6. Manufacturer's Record.—The last position is used for the manufacturer's private factory records.

Two wheels that have the same standard markings, but that have been made by different manufacturers, are almost sure to have a different grinding action. Remember this when it becomes necessary to change a wheel.

The various wheel manufacturers publish instruction books on their own output, and these books can be of great help in the selection of grinding wheels for particular types of work. If necessary, all the details of a grinding operation may be submitted to the wheel manufacturers for advice and recommendations.

Dressing Grinding Wheels

It can easily be seen that the surface of a grinding wheel might be worn down unevenly in the grinding process; it is also possible for stock particles removed in the grinding process to become imbedded in the surface of the wheel. As soon as the grains of the abrasive become dull, the grinding wheel should be DRESSED by cleaning out any imbedded stock and removing the grains which have become rounded through use. In order to reveal new cutting surfaces, the rounded grains are broken away by a dressing tool. The point of the tool is brought into contact with the face of the wheel by means of a special holder, and is then moved across the face of the wheel by hand or by mechanical means, until the desired surface is obtained.

TRUING a wheel is an entirely different process from dressing. A new wheel is trued when it is first mounted on its spindle, and ordinarily remains true until it wears out. The truing is done by starting the diamond cutting at the center, and working in both directions until the face is true.

The use of a coolant system is of great advantage in using a grinding wheel to grind dies, punches, and lathe, planer, and forming tools. It dissipates the heat generated by the grinding friction, and in this way prevents distortion of the material; it prevents pitting and scoring of the wheel; and it settles the dust that otherwise would be an annoyance and a source of danger to the operator. Frequently the use of a coolant makes it possible to remove more stock at each

pass of the wheel than could be removed in dry grinding; this in turn results in a reduction of the time required for cylindrical, internal, and surface grinding jobs. However, motor-driven coolant units (pumps and tanks) must be factory-installed.

ROTARY TYPE SURFACE GRINDERS

Cutter sharpening as it is known today had its beginning with the development of the machine tool. As the machine tool came into wider use, it became evident that there was need for another development along this line—a machine that would accurately grind milling cutters, as well as ream-

Figure 5–2.—Cutter and tool grinder.

ers, taps, forming tools, and other cutters. Today the various grinding machines are precision tools, with maximum ease of operation; with them the Machinery Repairman can perform the exacting operations required in maintaining the cutting tools which are part of his equipment. (See fig. 5–2.)

Rotary surface grinding machines are usually arranged with a plain type chuck feed handwheel, and are entirely hand-operated except for automatic reciprocation of the wheel-slide. However, a rotary grinder equipped with automatic hydraulic feed to the chuck can be operated on an almost automatic basis. Figure 5–3 illustrates one type of rotary surface grinder used by the Navy.

Description of setting-up procedure is based on grinding flat surfaces. The same method, however, with only a few variations, is followed in grinding convex and concave surfaces.

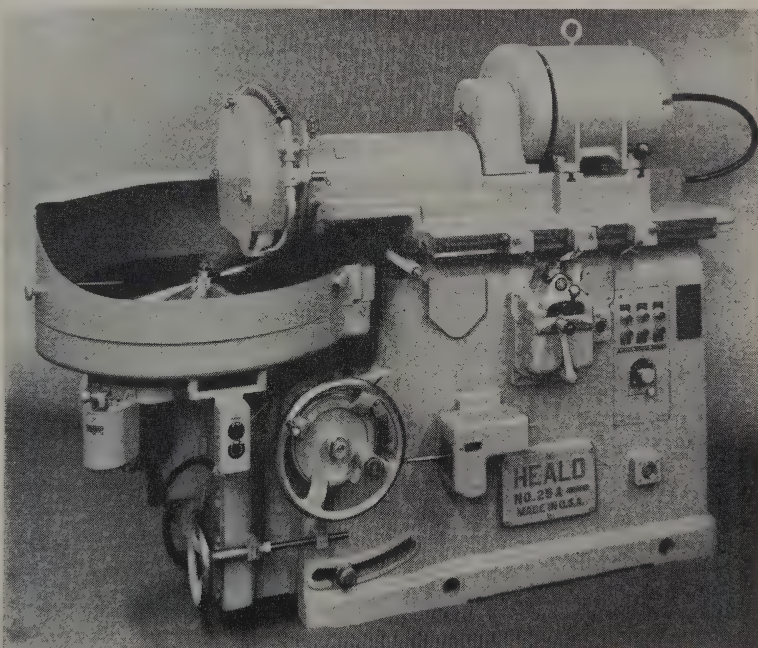

Figure 5–3.—Rotary type surface grinder.

Never begin actual grinding operations without first checking your machine. If it is not thoroughly clean, wipe it off with kerosene or with naphtha, and clean rags. Fill all the oil holes and cups shown on the manufacturer's lubrication chart. Make sure that the motors are idle, and that the wheel-slide and the speed control lever are both in the extreme right position. You are now ready to mount the grinding wheel which you have selected as the one most suitable for the work in hand.

Mounting the Grinding Wheel

Remove the collet and collet ring assembly from the spindle, and put the grinding wheel between the collet and ring, with a blotting paper or cardboard washer inserted on each side of the wheel. Before replacing the screws that will hold the collet, wheel, and ring together, be sure that the transfer marks on the collet and the ring are properly lined up. The collet and ring assemblies are balanced at the factory, and the transfer marks are provided as an aid in maintaining that balance.

In the circular slot in the face of the collet ring are three adjustable weights that can be used in balancing the collet, wheel, and ring assembly. It is recommended that this unit be given a final balancing operation before it is used, even though the transfer marks are lined up.

Make certain that the diamond is clear, and then mount the wheel and collet on the tapered end of the grinding wheel spindle, using the nut on the threaded end of the spindle to fasten it securely into position.

On some machines the position of the SPOUT and the amount of coolant flow are regulated by turning the coolant knob. On others the spout can be shifted after loosening the clamp knob, and the coolant supply is controlled by a lever cock in the coolant line.

Adjusting the Truing Unit and Truing the New Wheel

The first step in this truing process should always be to inspect the diamond, checking its sharpness and its tightness in the nib.

Now assume that you are using a machine equipped with a 16-in. or 24-in. magnetic chuck and furnished with a truing unit mounted on the chuck guard, as shown in figure 5–3. Adjust the knob to the midway position. Insert the diamond in the holder and lock it in place with the set screw. Place an unground piece of work on the magnetic chuck. Start the wheel-slide hydraulic pump motor to permit positioning the wheel-slide. Operate the chuck feed handwheel so that the grinding wheel just clears the surface to be ground, the wheel-slide being positioned by operating the hydraulic reverse lever and throttle. The wheel-slide moves in the direction in which the reverse lever is thrown; moving the throttle from right to left increases the speed of the wheel-slide, the wheel-slide coming to a full stop when the throttle is moved to the extreme right position. Adjust the threaded diamond holder vertically so that the diamond will satisfactorily true the face of the grinding wheel. Start the grinding wheel spindle motor, turn on the coolant, and then run the wheel-slide in and back at slow speed past the diamond, thus truing the wheel.

Loading Work on the Magnetic Chuck

When concentric grinding marks are desired, only one piece of work can be ground at a time and it must be held at the center of the chuck. For most work, however, the number of pieces that can be ground is limited only by the number that can be placed on the chuck, provided each piece overlaps at least part of two poles of opposite polarity, or provided that a retaining ring is placed on top of the chuck and the work is loaded inside the ring. When thin work must be ground, the retaining ring is especially useful in keeping the work from sliding on the chuck. Some parts may be so irregular in shape that it is impossible to clamp them on a standard magnetic chuck, and in such cases a special top plate attached to the top of the chuck must be used. If the work is so small that it will not properly overlap opposite poles, a chuck with concentric poles should be used. In this

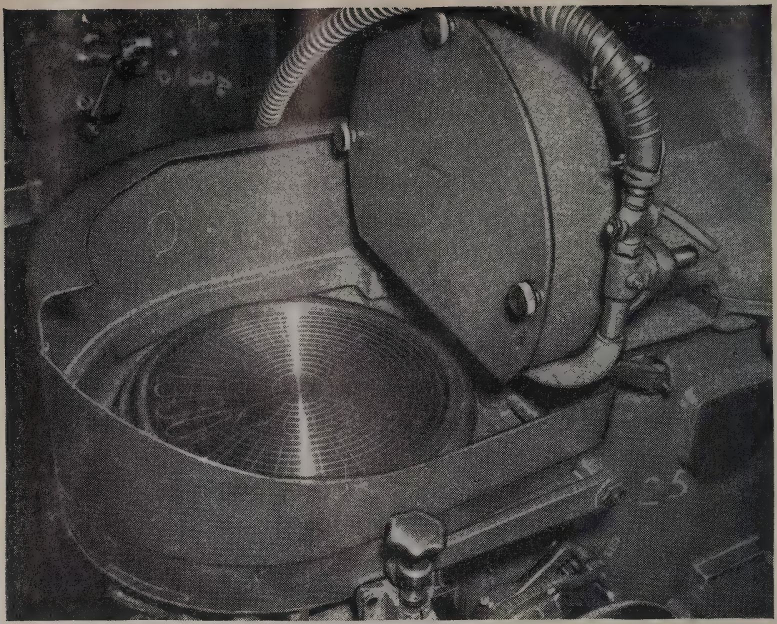

Figure 5–4.—Magnetic chuck.

case, however, the use of a retaining ring will permit grinding a great many parts at one time, regardless of the type chuck in use. When using a retaining ring, it is advisable to load the entire area within the ring, or at least to have a continuous ring of parts inside the inner edge of the ring. (See fig. 5–4.)

If the machine is equipped with a control lever, the work is clamped to the chuck by turning the control lever until a latch is engaged. To unclamp the work, disengage the latch and allow the control to return to the OFF position. This demagnetizes the work as well as the chuck and will take several seconds, so the work should not be moved while the lever is in motion.

A slightly different procedure is used if the machine is equipped with a drum switch instead of a control lever. To clamp the work, turn the switch handle to HOLD and allow the safety catch to engage. To unclamp the work, turn the

handle to RELEASE and then immediately to OFF. For thin pieces it will be necessary to repeat this several times. Do not leave the handle at RELEASE more than an instant or the work will be remagnetized.

Caution: A wrist watch should not be worn while operating any machine where a magnetic chuck is used, because of the danger of magnetizing the watch.

Setting the Grinding Stroke

The length of the grinding stroke is determined by several factors; for example, when grinding a large surface, about one-third of the wheel should remain on the outer edge of the work when the table is reversed, and about two-thirds of the wheel should remain on the inner edge. If the wheel is wider than the work, about one-half of the wheel width should remain on the ground surface.

In grinding work with shoulders, make sure that the amount of wheel withdrawal on the edge opposite the shoulder does not exceed one-half the wheel width; and provide sufficient relief at the shoulder to permit the wheel to pass beyond the ground surface.

For the grinding stroke, set the table dogs so that the latches are lowered. Move the right-hand dog to the right till it is out of the way; then load the work on the chuck, and run the table in until the work clears the face of the wheel. Make certain the wheel will clear the work, then run the table in until the wheel is properly positioned. Adjust the position of the dog so that the latch trips the reverse lever. The chuck should not be allowed to rotate at this time.

Slide the left-hand dog to the left out of the way, then reverse the table to the right until the wheel is properly positioned at the other edge of the work. Adjust the dog until the latch trips the reverse lever. The table should be traversed a few times at approximate grinding speed (using the THROTTLE lever to control the feed) to make certain that the wheel is in the proper position when the table

reverses. Make the final adjustments, and lock the dogs against slipping.

On some machines the dog can be moved by pulling down and then sliding it as desired, while finer adjustments are obtained by turning the knob. On other machines the dog must be unclamped by loosening two clamp nuts with a hexagon wrench before the dog can be shifted. To obtain a finer adjustment, tighten the nut on the block that carries the adjusting screw, then turn the knob. When properly located, tighten the dog clamp-nut. (The function of both types of dogs is identical once the set-up has been made.)

Setting Speeds and Feeds

How speeds and feeds should be set is determined by the individual characteristics of the job in hand, such as surface area, number of parts to be ground in the same chucking, material, hardness, tolerances, finish, stock, etc.

The hydraulic speed control lever can be adjusted to give any wheel-slide speed from 0 to 20 ft. per minute. Stop screws inserted in the various holes on the speed control quadrant will enable the operator to quickly and accurately obtain exactly the same roughing, finishing, and truing speeds for any part ground. To bring the speed control lever beyond the stop screws, it is merely necessary to pull out the handle.

Unless an automatic hydraulic feed to the chuck is furnished, chuck feeds are manually controlled. Chuck speeds may be varied to any one of four speeds by means of a control knob.

Setting Feed Box Knobs

The amount of stock to be removed determines the setting of the feed box adjustments. When setting feed box knobs, start the table and, while it is reciprocating, use the wheel-slide lever to feed the slide down by increments until a workpiece has been cleaned. (The FEED knob should be at OFF so the slide will not feed automatically.) Stop the machine and check the amount of stock remaining.

For example, assume that 0.015 in. remains after the piece is ground to clean, and that 0.012 in. can be removed at a rapid feed rate (say 0.0006 in. per feed impulse) but that the last 0.003 in. of stock must be ground at the minimum feed rate of 0.0002 in. per impulse.

If the machine is automatic there is a RETRACTION knob. Push it in and turn it until the RETRACTION dial stops at 15, the number of thousandths of an inch that the wheel must feed. The wheel retracts automatically to its original position after the work has been ground to size.

On the plain and power traverse machines or any other which does not have the automatic retraction feature, the setting will have to be done manually. Turn the FEED knob to the position desired, so the feed will occur automatically; then turn the handwheel on the FEED BOX to 15. Each graduation on the dial equals 0.001 in. as indicated by the numbers, and each graduation is subdivided into five parts equivalent to 0.0002 in. each.

Now turn the COARSE FEED knob to 3. This sets up the feed mechanism so that each impulse will feed the slide down three notches of the feed ratchet and, since each notch feeds 0.0002 in., the total amount of feed at each impulse will be 0.0006 in.

Since the example requires the last 0.003 in. of stock to be removed at the minimum rate, now turn the FINE FEED knob to 3. Before grinding, make certain that the stop knob is down.

Start the table, and while it is reciprocating in the grind stroke, the wheel will feed down automatically at the rate of 0.0006 in. per feed impulse for a distance of 0.012 in. At each impulse the handwheel will turn back three small graduations on the dial. When the dial reads 3, the rate of feed will automatically change to 0.0002 in. and the handwheel will turn back one small graduation per impulse until the handwheel reaches the stop and the dial reads zero. Now, on the automatic machine, the slide will retract to its original position and the dial will read 15 again. On the plain machine, the slide must be returned manually by turn-

ing the handwheel back to 15. On the power traverse machine, the slide can be returned by using the wheel-slide lever.

You have still to determine the exact amount of compensation for wheel wear. On the automatic machine, when the slide has retracted, measure the first workpiece and determine how much was actually removed. The difference between 0.015 in. and this amount should be the amount of wheel wear that took place during grinding. Turn the compensation knob one click for each 0.0002 in. compensation required. Each click will turn the handwheel one small graduation. Do this each time that work is loaded.

On the plain and power traverse machines, determine the amount of compensation in the same manner. When the handwheel dial reaches 0, turn the compensation knob the correct number of clicks. Then continue grinding, feeding the wheel manually by means of the wheel-slide lever until the dial reaches 0 again.

Dressing the Wheel

It is usually not necessary to dress the wheel after each piece or group of pieces has been ground. However, when dressing is necessary, move the THROTTLE lever to CLOSED; turn the diamond retraction collar counterclockwise until it stops, so as to bring the diamond up under the wheel; and then pull the THROTTLE lever out and to the right to DRESS. The table will run out at a speed regulated by the DRESS knob. The diamond should be adjusted by turning the diamond adjusting knob until the diamond dresses the wheel lightly.

Each click of the diamond adjusting knob equals 0.0002 in. feed of the diamond. When the compensation knob is turned for the next piece to be ground, the amount the wheel was dressed must be added to the regular amount of compensation for wheel wear.

Grinding Concave and Convex Surfaces

Machines are equipped with either a Zero Setting Device or an Angular Setting Device. The latter is furnished only

as a special attachment and is used for accurately locating the swivel bracket and spindle when tilting the chuck to grind concave or convex surfaces. Tables showing the gage lengths for different angles are supplied by the manufacturer.

To set the chuck exactly on zero in order to grind a surface exactly parallel with the top surface of the chuck, loosen the four clamp screws, fit the gage body over the pin on the table, and turn the handwheel until the pin on the cradle is against the other end of the gage. Then tighten the clamp screws. If the Angular Setting Device is used, it must be arranged according to the book of tables for 0 degrees and 0 minutes, or for a length of 8.6986 in. For other angles, the Angular Setting Device MUST be used, and should be arranged according to the tables for the correct angle.

Concave and convex surfaces are ground exactly the same as flat surfaces except that only a single part can be ground at a time, and the work must be exactly centered with the chuck. Usually it is located on a pilot at the center, or inside a locating ring.

PLANER TYPE SURFACE GRINDERS

When starting the planer type grinder (see fig. 5–5) for the day's work, fill all the oil holes and cups shown on the lubrication chart. Before operating the oil-shot pump be sure to line up the two buttons indicated in the illustration (and the instruction plate attached to the machine). Most cutter grinders are individually motor-driven, with the starting buttons built into a compartment on the side of the bed.

Setting Up the Machine

The table is traversed by means of crank B (fig. 5–5), which operates through a 10 to 1 differential gearing, and moves the table from left to right when turned in a clockwise direction. One turn of the crank moves the table $\frac{3}{8}$ in. Front and rear control knobs (C represents the front knob) are connected directly to the pinion which engages the table rack, and cannot be used until the differential crank B is

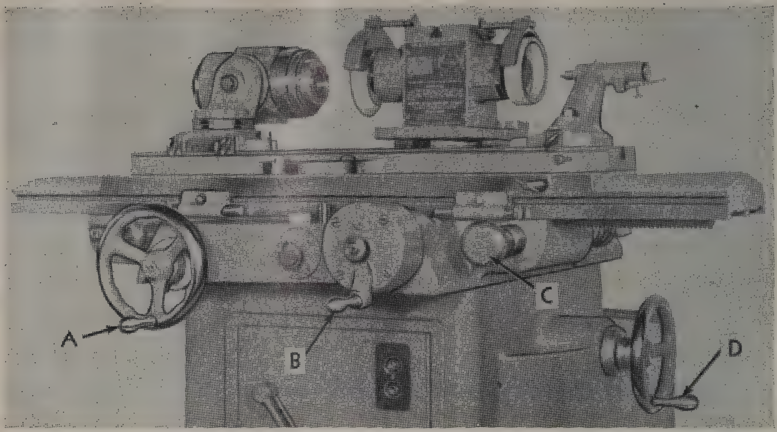

Figure 5–5.—Planer type surface grinder.

disengaged. To disengage this crank, pull out the knob in the center of the crank housing.

The table slide may be locked in position by tightening the hand screw clamp. Of course, the rear control traverse knob must be pushed in—that is, the pinion must engage with the rack.

For cross-adjustment, turn handwheel A in a clockwise direction, thus moving the table and saddle away from the grinding wheel. One turn of the handwheel moves the saddle $\frac{1}{8}$ in. The micrometer dial is graduated into 125 spaces, which is equivalent to 0.001 in. movement of the saddle for each space.

Another handwheel (on the reverse side of the machine) provides for the rear control movement of the saddle, and when turned in a clockwise direction moves the saddle and table towards the grinding wheel. The amount of motion per turn and the dial markings are the same as for handwheel A.

For vertical adjustment the handwheel D (fig. 5–5) is turned in a clockwise direction to move the column and wheelhead upward. One turn of the handwheel moves the wheelhead $\frac{1}{10}$ in. The dial is graduated into 100 equal divisions, each division being equivalent to 0.001 in. movement.

Another handwheel (not shown in fig. 5–5, but opposite D), which is a duplicate vertical control, is very convenient when working at the right-hand side of the machine. The dial markings and the amount of motion for one turn are the same as for handwheel D.

To swivel the wheelhead, loosen the screw and swivel the wheelhead to the desired setting; then retighten the screw. The wheelhead can be swiveled 120° in either direction.

When setting up the tailstock and workhead, tighten the thumb screws at the front of the unit before tightening the T-bolts that hold the unit to the table. This step is necessary because the tongues are a loose fit in the slot, and the unit must be lined up by locating against one side of the slot before being clamped down.

Spindle and Wheel Speed

A wheelhead motor, running at 3,425 rpm, drives the wheel spindle at 3,850 to 5,735 rpm. The drive is from a 2-step pulley on the motor shaft, through an endless belt, to a single-step pulley on the wheel spindle. When using 6-in. diameter

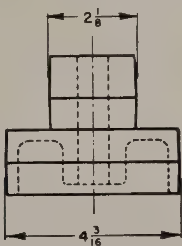

Figure 5–6.—Special pulley for 8-in. disk wheels.

grinding wheels, shift the belt to the small pulley; and when using smaller wheels, shift the belt to the large pulley.

Caution: When using 8-in. wheels, replace the pulley on the motor with the special pulley for wheels of this size (fig. 5–6). Place the belt on the small step. Large wheels may "explode" if run too fast.

To shift the belt from one pulley to another, or to tighten the belt, proceed as follows:

1. Stop the motor.

2. Open the door in the side of the bed.
3. Loosen the two hex head screws which hold the motor plate to the column.
4. Raise or lower the motor as required, and shift the belt.
5. Tighten the screws.

A grinding wheel will give the best cutting action and the longest service if surface speed is kept somewhere between 5000 and 6500 ft per minute. If the wheelhead motor should be changed for one with a different speed, it will be necessary to increase or decrease the pulley diameters, in order to keep the proper wheel speed. Surface speeds are figured from the following formulas:

$$\text{RPM spindle} = \frac{\text{rpm of motor} \times \text{diam pulley on motor}}{\text{diam pulley on wheelhead}}$$

$$\text{surface speed of wheel (ft/min)} = \text{rpm spindle} \times \frac{3.14 \times \text{diam wheel}}{12}$$

The SWIVEL TABLE may be adjusted forward or backward (considering the graduated end) for tapers up to 2 inches per foot, indicated by the scale in the sliding table. Loosen the two clamping bolts before turning the swivel adjusting screw (fig. 5–5).

For taper reamer jobs, accurate adjustments of the table may be obtained by clamping an indicator gage to the table T-slot, with the gage finger contacting the swivel table. Although the gage will not, of course, be graduated in taper per foot, it will help greatly to reduce the number of cut-and-try settings required to obtain an exact bearing the full length of the reamer.

Some grinding operations—for example, grinding saws of large diameter—will require greater swivel settings of the table. In such cases, you can rotate the swivel adjustment disengaging the pin ½ turn, and with the clamping bolts loose, swivel the table to the desired angle.

In the normal position of the swivel table, the center of the T-slot is 1¾ in. from the pivot stud, toward the wheel-

head. This is an important point to remember when sharpening heavy parts which overhang the table on the grinding wheel side. For these heavy cutters, it is advisable to swivel the table 180°, thereby bringing the **T**-slot 1¾ in. to the FRONT SIDE of the pivot stud. This shift in the position of the **T**-slot also shifts the center of gravity of the attachment and cutter 3½ in. toward the front table way, and eliminates any possibility of the set-up tipping toward the wheelhead.

When the table dogs are set as indicated in figure 5–5, a spring behind the plunger extending from each dog absorbs the shock at the end of the stroke, and also reverses the direction of table motion. This is the normal setting of the dogs for the majority of cutter-sharpening operations.

If a solid stop is desired, the dogs can be reversed, so that the knurled heads of the adjusting screws will contact the table stop.

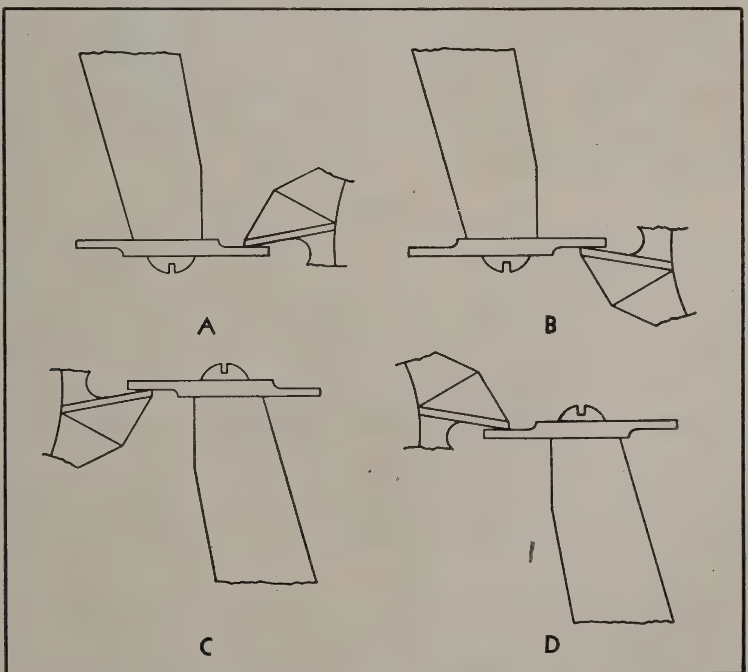

Figure 5–7.—Centering gage.

When the machine is being set up, the use of a centering gage will simplify the task of aligning a cutter tooth with the tailstock centers and with the center of the grinding wheel spindle. The gage may be placed either on top of the grinding wheelhead (fig. 5–7, A and B) or on the table (fig. 5–7, C and D). The opposite sides of the small diamond-shaped gage-plate are machined, and by swiveling the plate to bring the machined side in contact with the cutter tooth, both right-hand and left-hand cutters may quickly be centered.

Sometimes a preliminary step in the set-up requires that the center of the grinding wheel be the same height from the table as the tailstock centers—that is, that the column be set to zero. This is the reason for the zero line stamped on the face of the wheelhead. The setting may be accomplished by placing the centering gage on the table, and adjusting the column to match the zero line with the gage.

On the older-style machines, those without the bellows dust guard around the column, the zero line is stamped directly on the column. The zero setting can be obtained without the centering gage, merely by adjusting the column to match the zero line with the top of the housing.

Direction of Wheel Rotation

The standard direction of rotation of the grinding wheel is toward the cutting edge of the tooth, as indicated in figure 5–8A. The advantage of this set-up is that there are no burrs left on the cutting edges of the teeth, to be removed by a painstaking oil-stone operation. However, turning the spindle end for end will allow the wheel to rotate in the opposite direction (fig. 5–8B).

To change the direction of rotation, open the door on the side of the bed and remove the belt from the motor pulley, and then proceed as follows:

1. Loosen the clamp screws B and tighten the spreader screws C (fig. 5–8C).
2. Remove the screws A.
3. Remove the spindle assembly.

a. Turn it end for end and then replace it. The belt should be hanging loose on the spindle at this time.

b. On some grease-packed spindles there will be interference between the collet and the dust cover at one end and the adjusting nut and the inside of the dust cover at the other end. To correct this, face $\frac{1}{16}$ in. off the inside of the cover that interferes with the collet and at the other end add a $\frac{1}{16}$-in. spacer.

4. Replace the screws A. Make certain that the point of each screw fits easily into the drilled hole in the spindle retainer; otherwise you may spring the spindle.
5. Release the spreader screws C and lightly tighten screws B.

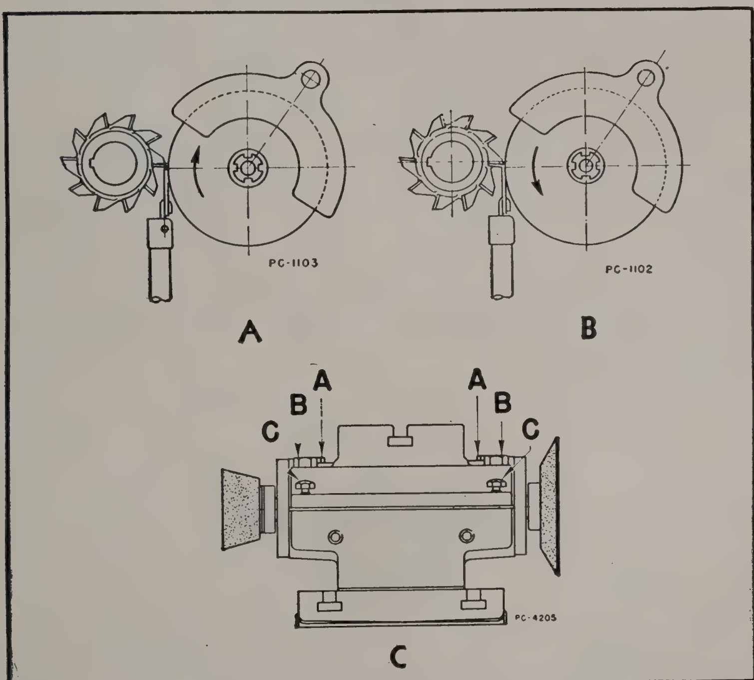

Figure 5–8.—A. Grinding wheel rotating toward the cutting edge. B. Grinding wheel rotating away from the cutting edge. C. Rear view of the grinding wheelhead.

You can now replace the belt on the motor pulley, and reverse the rotation of the motor.

To eliminate the possibility of the standard ¼-in. grinding wheel screw loosening with the rotation of the wheel, the hole in the end of the spindle should be drilled and tapped for a special screw. (This is not necessary, however, on new internal grinding attachment spindles.) Then this becomes the hole which is used in mounting the wheel.

Dressing and Truing the Wheel

For grinding a high-speed steel cutter or reamer a soft wheel is best, since it breaks down more easily and is therefore less liable to burn the cutter. But because a soft wheel wears away quickly, it is desirable to dress it often to obtain a good surface on the wheel, and a good finish on the work. A carbon steel cutter can be ground with a harder wheel of fine grain without drawing the temper.

To ensure a good cutting edge on a cutter, there must be a good finish on the clearance angles; therefore it will occasionally be necessary to true the grinding wheel. The wheel truing attachment illustrated in figure 5–9 is used for this operation. The diamond will produce a much better surface on the wheel if it is traversed uniformly; and to give the table a uniform motion a differential hand control is provided.

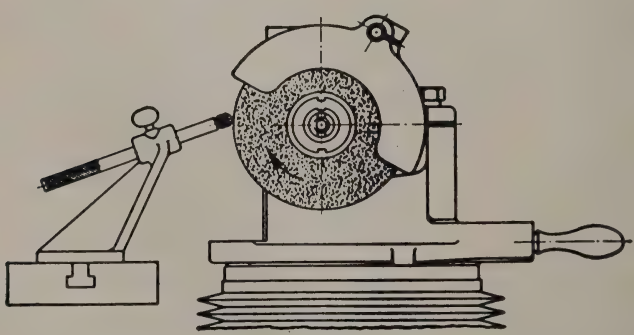

Figure 5–9.—Wheel truing attachment.

When truing a grinding wheel, never take a cut of more than 0.001 in. across the face of the wheel. After each pass of the diamond across the wheel, pause for a moment to allow the truing tool to dissipate some of the heat which is generated. This simple precaution will greatly increase the life of the diamond. It is more economical to reset a worn diamond than to continue using it with the possibility of damaging it beyond any further use.

Carbon steel and high-speed steel cutters should be ground dry. As long as the normal amount of stock is being removed, the heat generated will not be enough to cause checking. Sintered carbide cutters, however, should be ground wet.

Clearance Setting Devices

The clearance setting device for the left-hand tailstock must be set in conjunction with the dog. Clamp the dog to the mandrel, on which the cutter is mounted, with the pin inserted in the hole in the clearance setting plate. Loosen the thumbscrew, rotate the cutter to the desired clearance as indicated by the graduations, then tighten the thumb screw and remove the setting dog. This device is employed when using the cup wheel.

The three graduated diameters on the workhead will prove a convenience in setting up the job and in providing an accurate determination of clearance angles. These diameters are (1) the clearance setting dial at one end of the spindle housing, (2) the clearance and set-up graduations for the vertical swivel bearing, and (3) the clearance and set-up graduations for the horizontal swivel bearing. A knurled thumbscrew on the FRONT of the head tightens the spindle in position; the vertical and horizontal swivels are each tightened with a single wrench.

The Machinery Repairman will find that once he thoroughly understands the requirements for blades, he can readily fabricate other shapes to suit special types of cutters. Some typical tooth rest types of cutters are shown in diagram in figure 5–10 (A, B, and C), and shown in place on

the machine in figure 5–11 (A and B). A brief description of the uses served by each type is given below:

Figure 5–10A illustrates the straight blade, used with an adjustable holder for grinding straight fluted reamers, side mills, end mills, or any type of straight fluted cutter.

Figure 5–10B illustrates the tooth rest blade with a radius end; this type is used for sharpening shell end mills and small end mills.

Figure 5–10C illustrates the offset tooth rest blade, used for sharpening large-diameter coarse-pitch spiral-milling cutters, and for large face mills that have angular blade inserts.

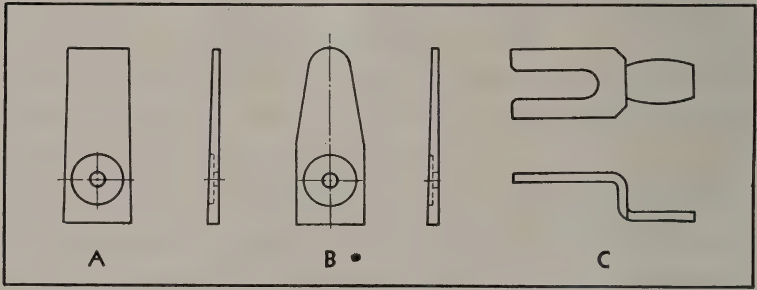

Figure 5–10.—Typical tooth rest blades.

The **L**-shape tooth rest blade for sharpening metal slitting saws and straight tooth plain milling cutters with closely spaced teeth is shown in figure 5–12. The blades are not carried in stock, but they can readily be made in the average shop. They should be formed of oil-hardening tool steel.

CYLINDRICAL GRINDERS

Plain Cylindrical Grinder

The plain cylindrical grinder is designed to do simple external grinding such as stepped external cylinders, tapers, concave and convex surfaces, and undercuts. On this machine a nonswivel wheelhead operates to and from the work table. The work table, however, may be swiveled for slight

tapers, and is traversed either by hand or by automatic feed control, by means of a mechanism at the base of the work table.

In order to accomplish form grinding on this machine, the grinding wheel must be dressed to the desired shape. The work is held between the footstock or dead center, and the workhead.

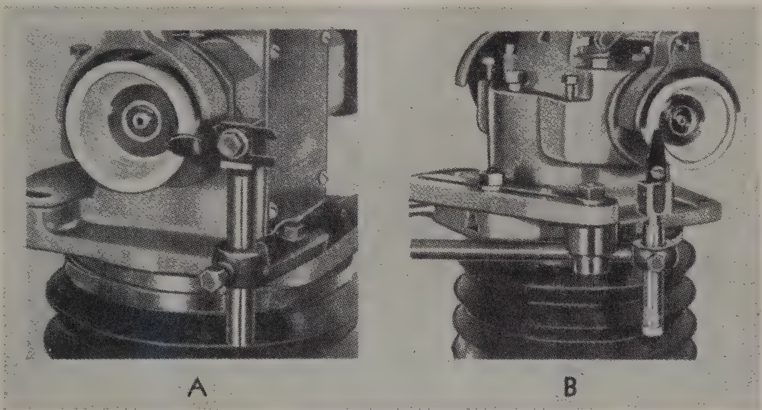

Figure 5–11.—A. Plain tooth rest. B. Universal tooth rest.

Universal Cylindrical Grinder

The Universal Cylindrical Grinder is capable of doing complex external cylindrical grinding. On this machine the wheelhead can be swiveled on its base, and fed to and from the table. The upper table is equipped with scales and adjusting screws for setting the table for slight tapers; steep tapers can be produced by swiveling the workhead on its base. The lower work table may be traversed either by hand or by power.

The operation for grinding tapers is very much the same as for grinding cylinders, except that the swivel table or wheel-slide is set to produce the correct angle. Usually, the graduations marked in degrees on the scale are one-half of the whole taper angle, and taper per foot indicates the whole taper angle.

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To grind steep tapers, swivel the workhead or dress the wheel at an angle. If the wheel is to be dressed it is necessary to set the diamond on the exact centerline of the wheel. This ensures dressing the correct angle, and also gives a straight surface on the wheel, rather than a surface which is convex or concave.

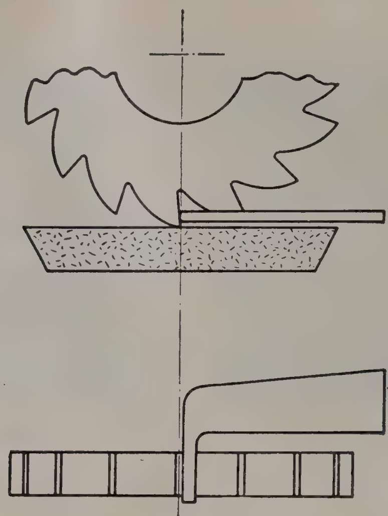


Figure 5–12.—L-shaped tooth rest blade.

When grinding a 60° conical point on a machine center, swivel the workhead 30°. Before starting grinding procedure make sure that the taper socket of workhead and the taper shank of the center are clean; after placing, center the work in the spindle dress grinding wheel and take a trial cut. Always observe how the wheel contacts the work. If the trial cut does not follow the original point, check the point with a flat or a cone-center gage, and make the necessary adjustments to ensure accurate results.

When a cone-center gage is used, the conical point of the machine center is given three stripes of prussian blue terminating at the apex of the cone, then the gage is carefully placed on the center with a slight twisting motion. When

the gage is removed the bearing spots will indicate whether or not the center corresponds with the gage.

After checking and making any necessary adjustments, proceed carefully with the grinding operation. The change in work speed due to steep taper will cause burning of the center point. This burning may be overcome by taking light cuts, by using a slow work speed and a flood of coolant, and by working the cut from point, back to the large diameter of the machine center.

Contour grinding, such as convex, concave, or a radius and an angle, may be accomplished by dressing the wheel to the desired shape.

Centerless Grinder

The centerless grinder is designed for the rapid production of plain external cylinder, external taper, or external profile work. It might be assumed, therefore, that the centerless grinder is purely a production machine. However, this is not the case, inasmuch as this machine possesses many characteristics that make it applicable for toolroom use.

The machine is rigidly built and is simple to operate. It eliminates the necessity of having to center-drill the ends of the work, and also eliminates the time required to load and unload the work properly between the centers of a cylindrical grinder. Allowing heavier cuts to be taken, it reduces the number of passes of the wheel on the work. From an operator's point of view, the important operating members are the grinding wheel, the regulating wheel, and the work rest.

The working principles of this machine are relatively simple. The action of the grinding wheel exerts a pressure on the work, forcing the work down on the rest and against the regulating wheel. The regulating wheel, which is actually a rubber-bonded abrasive wheel, rotates in a clockwise direction, causing the work to revolve in a counterclockwise direction. The grinding wheel, also rotating in a clockwise direction, operates continuously at about 6000

surface ft per minute, whereas the regulating wheel can be operated at from 12 to 300 rpm.

When grinding plain cylinders where the cylinder can be fed completely through the machine, the method of feeding the work is known as THROUGH FEED GRINDING. If the work must be ground to a shoulder, the method used is known as IN FEED GRINDING. Regardless of which method is used, the rate of feed is governed by the position of the regulating wheel axis with respect to the axis of the grinding wheel, and by the speed of the regulating wheel. For work that is straight, the regulating wheel ordinarily should be set from 3° to 4°, but this angle can be increased to as much as 6° if the work is badly warped or bent.

CUTTER GRINDING

By using only the standard workhead and tailstocks, without attachments, a variety of types of cutters can be ground on a Cincinnati No. 2 cutter grinder. Cutters that may be ground without the use of attachments include:

Plain Milling Cutters.
End Mills.
Shell End Mills.
Slotting Cutters.
Keyway Cutters.
Stagger Tooth Cutters.
Side Milling Cutters.
Angular Cutters.
Face Mills up to 8 in. diameter.
Saws up to 8 in. diameter.
Form Milling Cutters.
Taps.
Hobs.
Reamers.

Plain Milling Cutters

Since essentially the same method may be used for sharpening many cutters, it will be worth while to give in some detail the steps involved in setting up the machine and then grinding a specimen cutter. The plain milling cutter with helical teeth will serve very well as an example.

1. Adjust the saddle away from the wheelhead to allow plenty of space for the set-up. Clean the table and

the bottoms of the right- and left-hand tailstocks; then clamp the tailstocks on the table, spaced at the right distance for the arbor or mandrel used for the set-up.

2. Clean the arbor, collars, and cutter hole. Mount the collars on the arbor, lightly clamp them with the nut, and place the assembly between centers.
3. Fasten the wheel mount—collet and flared cup grinding wheel—to the right-hand end of the wheelhead spindle.
4. Swivel the wheelhead 89°.
5. Check the wheel speed, and make sure that the belt is on the large pulley.
6. Place the centering gage on the table, and align the axis of the wheelhead spindle with the tailstock centers. Use the vertical control handwheel to make required adjustments. Older machines without a bellows dust guard have a zero line stamped on the column, and a centering gage is not necessary for this step.
7. Mount the tooth rest assembly on the wheelhead, using the solid post type with offset blade.
8. With the centering gage on top of the wheelhead, and the tip of the gage directly in front of the rim of the wheel, adjust the tooth rest blade to gage height.
9. Traverse the saddle toward the wheelhead until one cutter tooth rests on the blade; then lock the table into position.
10. Clamp the clearance setting dog on the arbor.
11. With a cutter tooth resting on the tooth rest, lower the wheelhead until the desired clearance is indicated on the clearance setting dial. Closely spaced teeth may limit the amount of clearance angle obtainable.
12. Unlock the table and remove the clearance setting dog.
13. Run through the set-up, WITHOUT GRINDING. With one hand, traverse the table (using the rear control) ; with the other hand, hold the arbor just firmly enough to keep the cutter tooth against the blade.

14. Swing the master electrical switch, at the front of the machine, to the ON position. Stand away from the wheel and push the starting button. Allow the wheel to run for one minute or so.
15. Adjust the saddle until one cutter tooth lightly contacts the wheel. Grind one tooth. Rotate the cutter 180° and grind the opposite tooth. Check the two teeth with micrometers for taper.
16. Remove the taper, if any, by means of the swivel table taper adjustment.
17. Grind the remaining teeth. Do not remove more than 0.002 in. for roughing and 0.0005 in. for the final grind. Remember to adjust for wheel wear.
18. If the land is too wide, a secondary clearance of 3° to 5° can be ground. It should be about $\frac{1}{16}$ in. for average to large diameter cutters, and narrower for small cutters.

These steps are given in detail, and make it seem as if the grinding process would be a long one; but because of the convenience in making various adjustments, the time actually required for this cutter grinder set-up is surprisingly short.

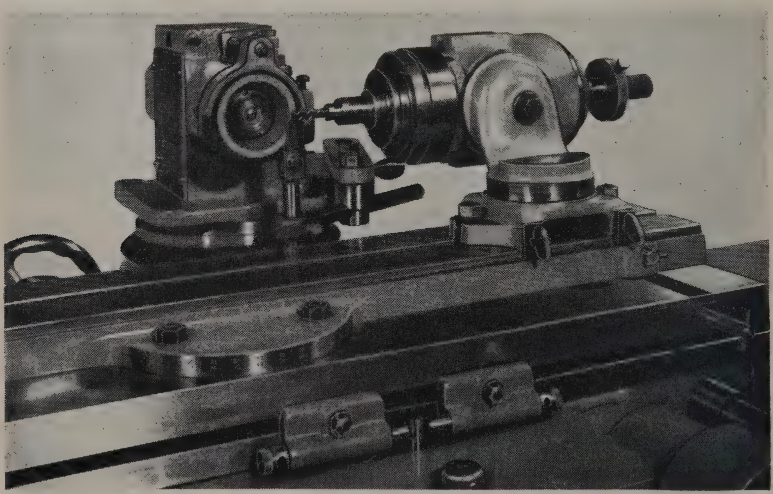


Figure 5–13.—Grinding a small end mill.

The flare cup wheel is used for the preceding grinding set-up. This type of wheel is used because it produces a flat land, instead of the curved land produced by the disk wheel, and it is the type preferred by most operators.

End Mills

Much the same practice is carried out when grinding an end mill as when grinding a plain milling cutter. The main difference is that the ends or face of the teeth and the corners must also be sharpened, requiring two additional set-ups. (See fig. 5–13.)

After grinding the periphery of the teeth, proceed as follows to set up for grinding the face of the teeth (instructions are for a right-hand cutter with undercut teeth):

1. Position the workhead on the table, and insert the cutter.
2. Fasten the wheel to the right-hand end of the spindle, true the wheel, and swivel the wheelhead 89°.
3. Place the centering gage on top of the wheelhead, and raise or lower the wheelhead a sufficient amount to bring the cutting edge of a tooth in a horizontal plane with the gage. This will at the same time center the cutting edge of the tooth with the center of the wheel.
4. Lock the workhead spindle in place.
5. Clamp the tooth rest in place on the workhead, resting the blade against the under side of the tooth to be ground.
6. Swivel the cutter downward to the desired clearance angle, and clamp it into position.
7. Lower or raise the wheelhead so that the tooth next to the one being ground will clear the wheel.
8. Loosen the workhead spindle thumbscrew, and proceed to grind. Remember to adjust for wheel wear.

Reset for the secondary clearance and grind, using the same procedure as outlined above. On large-diameter shell end mills, it is often a good idea to back off the faces of the teeth towards the center of the cutter, similar to the tooth of

a face mill. An angle of about 3° is sufficient, allowing a land $\frac{3}{16}$ in. to $\frac{5}{16}$ in. long.

It is important that as much care be used when grinding the corners of the teeth as when grinding the face or periphery; otherwise the cutting edges will dull rapidly, and a poor finish will result.

A damaged helical end mill may be salvaged by cutting off the damaged end with a cylindrical grinding attachment, as shown in figure 5–14.

For a right-hand mill with undercut teeth, grind the corners according to the following procedure:

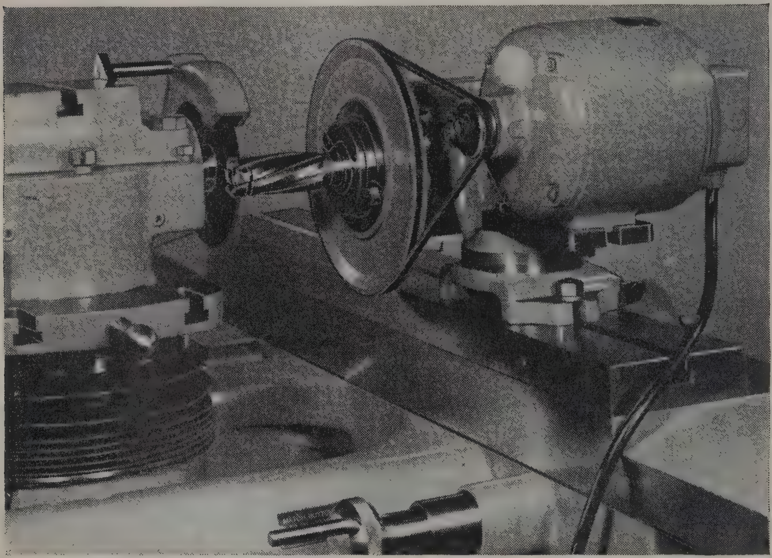


Figure 5–14.—Cutting off the damaged end of a helical end mill.

1. Swivel the workhead in the horizontal plane to the corner angle desired as shown by the graduations on the base (45° is the most common). (See fig. 5–15.)
2. Bring the upper part of the workhead back to zero on the degree readings.
3. Place the centering gage on the table and adjust the column to zero.

4. Place the centering gage on top of the wheelhead. Move the slide and rotate the cutter until the corner of one tooth just touches the gage. Lock the workhead spindle in place with the thumbscrew.
5. Set the clearance setting dial to zero. Loosen the spindle clamping thumbscrew and rotate the cutter by hand until the clearance setting dial indicates the desired clearance angle. Lock the workhead spindle in place.

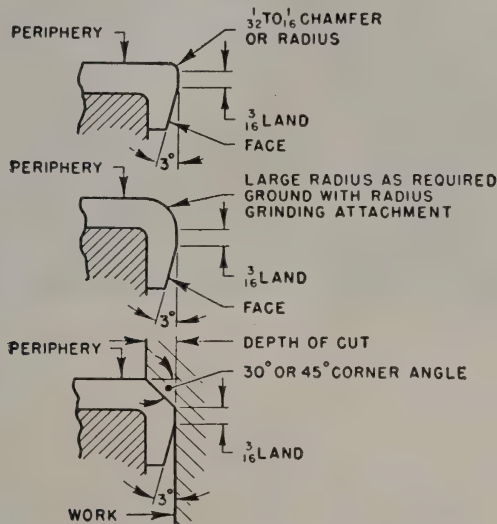


Figure 5–15.—Three types of corners for shell end mills and face mills.

6. Clamp the tooth rest in place on the workhead, resting the blade against the underside of the tooth to be ground.
7. Swivel the cutter downward to the same clearance angle as indicated on the clearance setting dial.
8. Loosen the workhead spindle clamping thumbscrew, and adjust the saddle to bring the cutter in position with the wheel.
9. Set the dog on the slide for the proper length of stroke, and proceed to grind.

The two angular settings given in steps 5 and 7 are necessary because the clearance angle on the diameter is being matched with the clearance angle on the face of the teeth.

If the teeth are radial, set the column at zero when grinding the ends of the teeth, and the cutting edge of the tooth will be aligned with the horizontal plane through the center of the wheel and the cutter.

With a left-hand cutter, the set-up for grinding the ends or face of the teeth is the same as outlined in the 8 steps for grinding end mills, EXCEPT for the changes in the FOLLOWING STEPS. Of course, the wheel is placed on the left-hand end of the spindle, and the duplicate controls at the right-hand rear are used.

3. LOOSEN the screw through the centering gage plate, and swivel it 180°. LOWER the wheelhead to bring the cutting edge of the tooth into a horizontal plane with the gage.
6. TILT THE WORKHEAD UP to the required clearance angle, and clamp it in place.
7. RAISE THE WHEELHEAD so that the bottom of the rim of the wheel will clear the tooth next to the one being ground.

End Teeth

For sharpening the end teeth of a shell end mill, the cutter is mounted on an arbor set in a taper shank mill bushing. The bushing is inserted into the taper shank mill bushing sleeve held in the universal head. To obtain the desired clearance angle, swivel the head in the vertical plane; and swivel it slightly in the horizontal plane to grind the teeth low in the center of the cutter. The cutter is turned until one of the teeth is horizontal and the wheel is raised until that tooth can be ground without interference. (See fig. 5–16.)

Peripheral Teeth

For grinding the peripheral teeth of a spiral end mill, the end mill is supported between the center head and the foot-

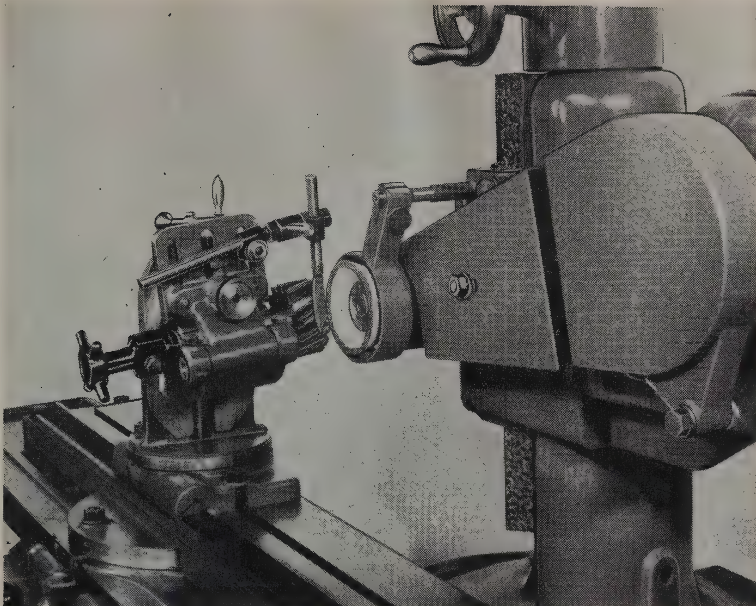


Figure 5–16.—Grinding the end teeth of a shell end mill.

stock fitted with the reamer grinding center. The tooth rest is mounted on the wheel spindle slide. The spindle slide upright is swiveled 90° to the table and, if necessary, is then turned back just enough to allow the trailing edge of the wheel to clear the cutter during the grinding operation. (See fig. 5–17.)

Spiral Cam Locks

For sharpening the end teeth of a right-hand spiral cam lock end mill having a standard milling machine taper shank, the cutter is held in a regular cam lock adapter. Using the end-mill sharpening attachment in conjunction with the tooth rest (fig. 5–18) ensures rapid and precise indexing.

Side Milling Cutters

Figure 5–19 shows a side milling cutter—that is, one which cuts with the sides as well as the periphery of the teeth.

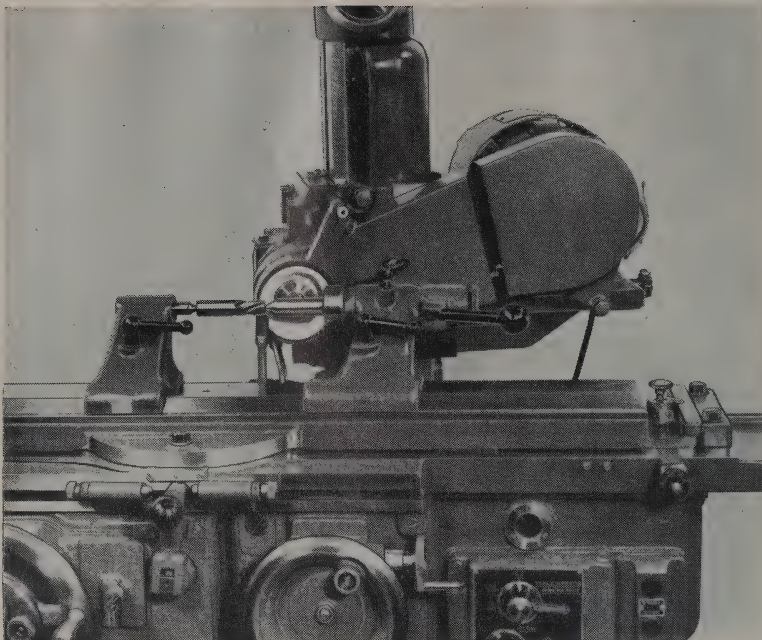


Figure 5–17.—Grinding a spiral end mill.

Basic instructions for grinding a side milling cutter are the same as for the plain milling cutter with helical teeth.

After grinding the periphery of the teeth in the regular manner, set up for grinding one side of the teeth (as shown in fig. 5–19) in the same manner as described under grinding shell end mills; then grind the other side of the teeth.

This type of cutter often shows a tendency to chatter. To correct this fault the cutting clearance on the sides of the teeth can be reduced to as low as 1°, especially if very little cutting is being done by the sides. As an additional remedy, the cutter teeth can be ground to a slight relief angle.

Stagger Tooth Cutters

Because cutters of this type present several problems, instructions for grinding are given in detail.

Contrary to the opinions and practice of many, the PRIMARY

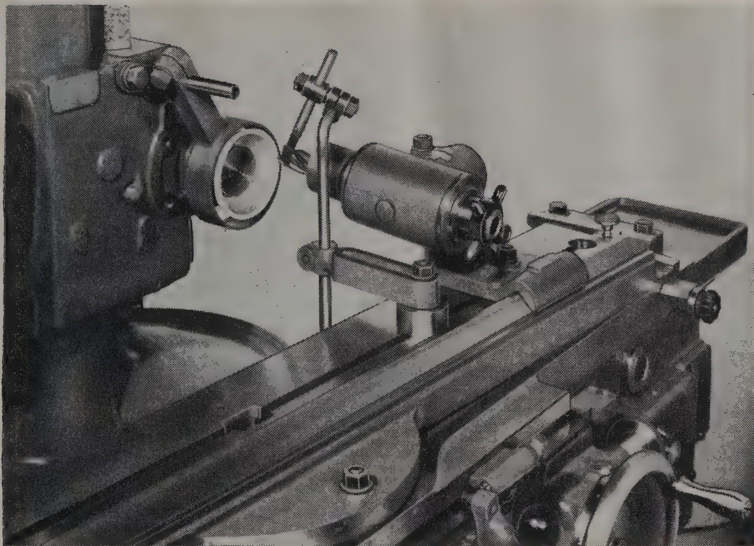


Figure 5–18.—Grinding a spiral cam lock.

CLEARANCE can be ground on all the teeth in one setting almost as quickly as a straight tooth slotting cutter. Proceed in the following manner for this set-up:

1. Adjust the saddle away from the wheelhead to allow plenty of room for the set-up. Clean the table and bottoms of the right- and left-hand tailstocks. Clamp them to the table, with an extra T-bolt between them, and properly spaced for the arbor or mandrel used for the set-up.
2. Clean the arbor, collars, and cutter hole, mount on the arbor, lightly clamp with the nut, and place the assembly between centers.
3. Fasten the wheel mount—collet and flared cup grinding wheel—to the right-hand end of the wheelhead spindle.
4. Swivel the wheelhead 89°.
5. Check the wheel speed. The belt should be on the large pulley.

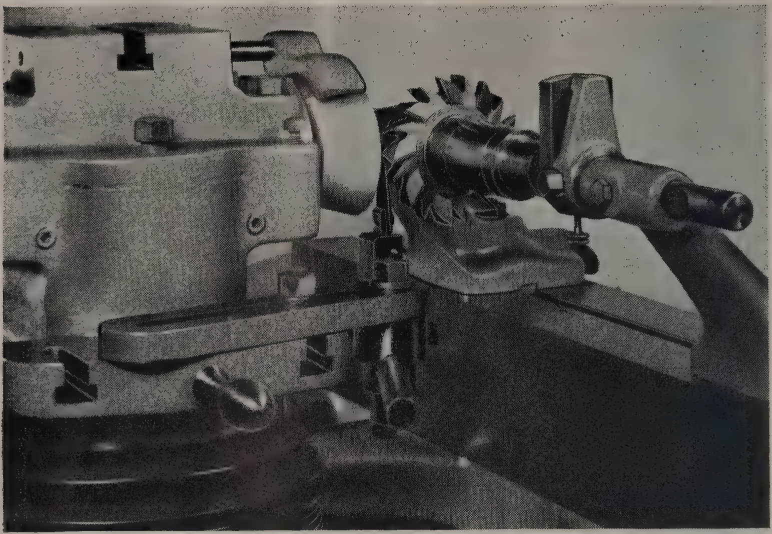


Figure 5–19.—Side milling cutter.

6. Place the centering gage on the table, and align the axis of the wheelhead spindle with the tailstock centers. Use the vertical control handwheel to make any needed adjustment. On older machines, a zero line is stamped on the column, and a centering gage is not necessary for this step.
7. Mount the universal tooth rest on the wheelhead. The inverted-**V** blade is preferred; this blade has an included angle which is at least 10° less than the included angle of the cutter teeth.
8. With the centering gage on top of the wheelhead, adjust the tooth rest blade to gage height, with the highest point of the blade directly in front of the rim of the wheel.
9. Traverse the saddle toward the wheelhead until one cutter tooth rests on the blade. Lock the table into position.
10. Clamp the clearance setting dog on the arbor.
11. With the cutter tooth resting on the tooth rest, lower

the wheelhead until the desired clearance is indicated on the clearance setting dial. Closely spaced teeth may limit the amount of clearance angle obtainable.

12. Unlock the table and remove the clearance setting dog.
13. Run through the set-up without grinding. With one hand, traverse the table (using the rear control), and with the other hand hold the arbor just firmly enough to keep the cutter tooth against the blade.
14. Swing the master electrical switch, at the front of the machine, to the ON position. Stand away from the wheel, and push the starting button. Allow the wheel to run for one minute.
15. Adjust the saddle until one cutter tooth lightly contacts the wheel. Grind one tooth as the table traverses (for example, from left to right); and on the return traverse of the table, grind the next tooth of the opposite helix. Continue until all teeth are ground to the same height.
16. After grinding around the cutter once, check both series of teeth with an indicator gage. If the teeth are not the same height, slightly adjust the tooth rest blade toward the high side, and regrind.

SECONDARY CLEARANCE angles of 3° to 5° are recommended; however, in the case of staggered tooth slotting cutters, secondary clearance angles are 20° to 25°. This is done to prevent regrinding of the secondary clearance each time the primary clearance is ground. This operation requires two set-ups of a different type; the first set-up follows:

1. Change the tooth rest from the wheelhead to the table, using the T-bolt previously placed between the tailstocks. Use the micrometer adjustable tooth rest, and an L-shaped blade.
2. With the centering gage on the table, center the wheelhead; place the centering gage on top of the wheelhead, and rotate the cutter until one tooth contacts the lip of the gage. Mark that point on the cutter, and lock the table in position.

3. Adjust the clearance setting dial so that the 150° mark on one side of the graduations matches the zero line, and clamp the clearance setting dog to the arbor. Rotate the cutter for 20° to 24° secondary clearance.
4. Swivel the table as much as your judgment dictates to grind a straight land, which will probably not exceed 7°. Swivel right or left, depending upon the helix angle of the tooth to be ground.
5. Adjust the tooth rest blade under the tooth to be ground, at the point marked when centered up.
6. Unlock the table and remove the clearance setting dog.
7. Grind the secondary clearance to about $1/16$ in. width of land.
8. Repeat for every tooth having the same land of helix angle.
9. Repeat the set-up, with the table swiveled to the opposite direction, for all teeth of the opposite helix angle.

The SIDES of a staggered tooth cutter should be ground only when it is desired to reduce its width. The second set-up is as follows:

1. Clean the table and bottom of the workhead. Clamp this unit to the table.
2. Mount the cutter on a stub arbor. Equipment of this type is usually available for the cutter grinder only.
3. Use the same wheel mount as employed for the preceding grinding operations.
4. Place the centering gage on the wheelhead, and align the edge of one tooth parallel with the top of the table.
5. Mount the tooth rest on the workhead, with the tooth rest blade supporting the tooth to be ground.
6. Swivel the workhead down to the desired primary clearance angle.
7. Raise or lower the wheelhead to allow the wheel to clear the tooth next to the one being ground.
8. Grind primary clearance, all teeth.
9. Repeat steps 6, 7, and 8 of the first set-up.

The set-up for grinding a tap and grinding a radial tooth form milling cutter are essentially the same, since they are both straight tooth form relieved cutters. The set-up procedure is as follows:

1. Fasten the extension and the disk wheel to the left-hand end of the spindle.
2. Shift the belt to the small step of the pulley.
3. Swivel the wheelhead 90°.
4. True the wheel with a diamond.
5. Place a straightedge across the face of the wheel, and line up with the tailstock centers. A simple gage for this operation can be made at little expense.
6. Place the tap between centers.
7. Fasten the tooth rest to the table, with the square end blade against the back of the tooth to be ground.
8. Adjust the tap to the wheel with the micrometer adjustment on the tooth rest, and grind.

For best results, the backs of the teeth should be ground before the faces.

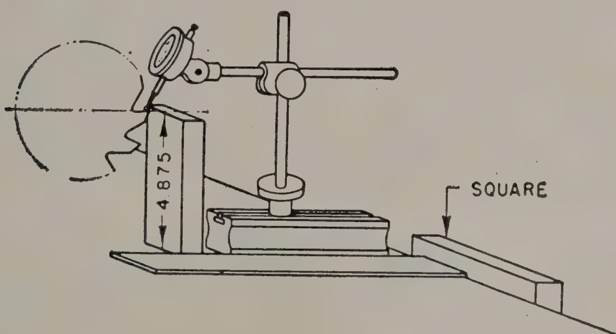


Figure 5–20.—Testing for accuracy of grinding.

In cutters of this type the teeth must be ground radially, or else the tooth form will be changed. A simple and effective means of testing is shown in figure 5–20. The block is

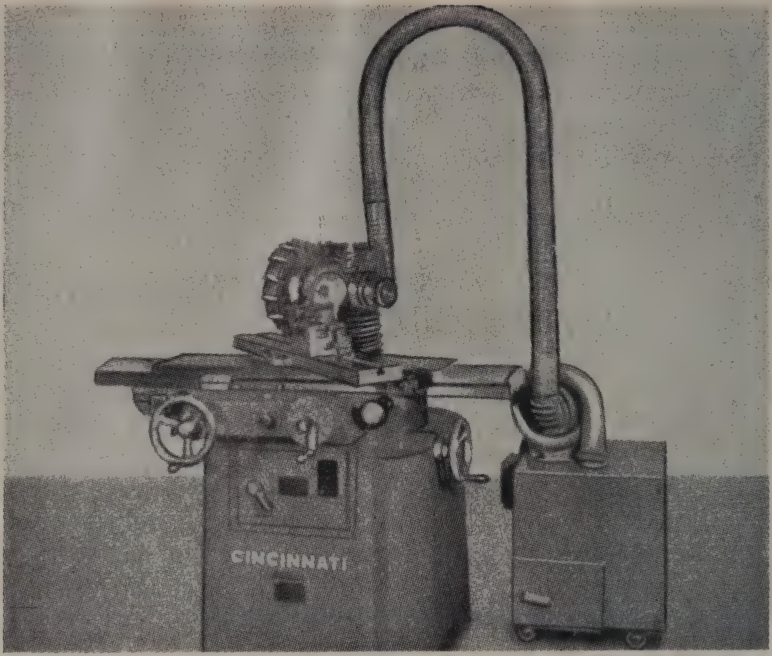


Figure 5–21.—Dust collector for isolated machines.

the same height as the tailstock centers. Set the indicator dial to zero when indicating this block, remove the block, and turn the cutter until the outer edge of the tooth touches the indicator pointer and registers zero on the dial. Then move the indicator straight in towards the center of the cutter, and note the reading. If the tooth is ground radially, the indicator will remain at zero.

SAFETY PRECAUTIONS

The space about a machine should be kept light, clean, dry, and as free as possible of attachments, loose parts, or any kind of obstruction. As a health measure, dust collectors should be connected to all machines. Those machines which are grouped together may be serviced by a central system; isolated machines should be equipped with some kind of individual unit. Several types of such individual dust collectors are available; one type in common use is shown in figure 5–21.

Inspection and Storage of Wheels

Competent men should be assigned to the mounting, care, and inspection of grinding wheels.

Immediately upon receipt, all wheels should be inspected closely to be sure that they have not been injured in transit. Inspect for cracks by tapping, while they are suspended, with a light implement, such as the handle of a screw driver. Wheels must be dry and free from sawdust when applying this test. Organic-bonded wheels do not emit the same clear metallic ring as do vitrified and silicate wheels.

Extreme care should be used in the STORAGE of wheels; they should be stored in a dry place, and pegs should be used to support the wheels in the storage racks.

Rules for Operating New Wheels

Run all new wheels at full operating speed for at least one minute before applying the work; during this time the operator should stand at one side.

Work should not be forced against a cold wheel, but applied gradually, giving the wheel an opportunity to warm and thereby minimizing the chance of breakage. This applies to starting work in the morning in cold rooms, and to new wheels which have been stored in a cold place.

Grinding on the flat sides of straight wheels is often hazardous and should not be allowed on such operations when the sides of the wheel are appreciably worn, or when any considerable or sudden pressure is brought to bear against the sides. Care should be taken to tighten the spindle end nut just enough to hold the wheel firmly; otherwise the clamping strain is liable to damage the wheel.

Operating Precautions

The following precautions must be observed in operating machines:

1. Eliminate the possibility of eye injury by WEARING GOGGLES or some approved form of eye shield.

2. Do not run a machine without WHEEL GUARDS.
3. All abrasive wheels must be mounted between flanges.
4. Washers or flange facings of compressible material must be fitted between the wheel and its flanges. If blotting paper is used, it should not be thicker than 0.025 in. If rubber or leather is used, it should not be thicker than 1/8 in. If flanges with babbitt or lead facings are used, the thickness of the facing should not exceed 1/8 in. The diameter of the washer must be the same size or slightly larger than the flange diameter.
5. All surfaces of wheels, washers, and flanges in contact with each other should be free from foreign material.

QUIZ

1. What type of grinding machine should be used for sizing reamers and cutters?
2. What are the two types of cylindrical grinders?
3. What is of primary importance in any grinding operation?
4. What are the abrasives commonly used in grinding wheels?
5. Should hard or soft wheels be used for grinding celluloid? For grinding hard materials of low tensile strength?
6. What is a combination wheel?
7. To what does the term wheel structure refer?
8. What bonding material is most commonly used in wheels for general toolroom use?
9. Wheels used to cut grooves should be bonded with what material?
10. What characteristics of wheels are indicated by manufacturers' markings?
11. Would grain size 150 be coarse or fine?
12. If two wheels made by different manufacturers have the same standard markings, will they have exactly the same grinding action?
13. What is meant by dressing a wheel?
14. The use of a coolant serves what three purposes?
15. How should the grinding wheel be mounted on the rotary surface grinder?
16. What is the purpose of the transfer mark on the collet and the ring?
17. What should be the first step in the process of truing a new wheel?

18. How should the threaded diamond holder be set for truing a wheel?
19. For most types of work, how many pieces can be ground at a time on the magnetic chuck?
20. On a machine equipped with a control lever, how is the chuck and the work demagnetized after a grinding operation?
21. On a machine equipped with a drum switch, how is the work demagnetized?
22. When shoulders are to be ground, how should the amount of wheel withdrawal on the edge opposite the shoulder compare with wheel width?
23. What is used to control the feed when the table is traversed to try out the machine before grinding?
24. The hydraulic speed control lever can be adjusted to give what range of wheel-slide speeds?
25. What use is served by the stop screws on the speed control quadrant?
26. When stock is being ground, what controls the amount to be removed?
27. What is the purpose of the compensation knob on an automatic grinding machine?
28. Which setting device—zero or angular—is used on most machines?
29. When curved surfaces are to be ground, how many pieces can be ground at a time, and how is the work located on the chuck?
30. On a planer type surface grinder, how is the table slide locked into position?
31. When the column and wheelhead of a surface grinder are being vertically adjusted, what distance does the wheelhead move with each turn of the handwheel?
32. Describe the drive from the wheelhead motor to the wheel spindle.
33. When 8-in. wheels are used, what change should be made in the drive?
34. What range of surface speed ensures the best cutting action and the longest service from a grinding wheel?
35. What are the formulas for calculating surface speed of a wheel?
36. The swivel table on a planer type surface grinder may be adjusted to accommodate how much of a taper in the stock?
37. When heavy parts are to be sharpened, what is the advantage of swiveling the table 180°?

38. What is the purpose of the spring behind the table dog plunger?

39. What is used to simplify the task of aligning a cutter tooth with the tailstock centers and with the center of the grinding wheel spindle?

40. What is the reason for the zero line on the face of the wheelhead?

41. What is the standard direction of rotation of a grinding wheel?

42. How can the direction of the wheel be reversed, when necessary?

43. Why is a soft wheel best for grinding a high-speed steel cutter?

44. When truing a grinding wheel, why should you pause after each pass of the diamond across the face of the wheel?

45. Should carbon steel cutters be ground wet or dry?

46. What are the three graduated diameters on the workhead of the planer type surface grinder?

47. What type of grinder is used for concave and convex surfaces, tapers, and undercuts?

48. Complex external cylindrical grinding is usually done on what type of machine?

49. How is taper angle indicated on the Universal grinders?

50. What should be done to overcome the burning of the center point that results from change in work speed due to the steepness of the taper?

51. What are the three most important operating parts of the centerless grinder?

52. On the centerless grinder, what governs the rate of feed?

53. What is meant by THROUGH FEED GRINDING? By IN FEED GRINDING?

54. Which, if any, of the following require the use of special grinding attachments: keyway cutters; hobs; 12-in. diameter saws?

55. Why does grinding an end mill require two additional set-ups after the preliminary sharpening?

56. For sharpening the end teeth of a shell end-mill, how is the cutter mounted?

57. In grinding a spiral cam lock, what is the advantage of using the end-mill sharpening attachment in conjunction with the tooth rest?

58. When side milling cutters are being used, what can be done to reduce chatter?

59. Why are such large secondary clearance angles (20° to 25°) recommended for staggered tooth slotting cutters?

60. How should new wheels be stored?

CHAPTER 6

METAL FINISHING PROCEDURES

Although not among the primary duties of the Machinery Repairman, the heat-treating, resurfacing, and building up of metal surfaces are allied closely with the manufacture and repair of machinery parts and are, therefore, important factors in rounding out your knowledge of complete repair procedures.

In many cases you may find it necessary to have machine parts or tools heat-treated before you can complete a machining operation. In order to explain to the Metalsmith what you desire in the way of heat-treating a certain machine part, it is necessary for you to know the theory of, the standards for, and the procedures used in heat-treating, hardening, and resurfacing metals. In some cases it may even be necessary for you to accomplish a measure of the work yourself.

This chapter deals with (1) some of the theory, standards, and procedures used in heat-treating, (2) methods of resurfacing, and (3) the latest methods used in metalizing.

FUNDAMENTALS OF HEAT TREATMENT

When the conditions of HEATING and COOLING a metal or alloy in the solid state are so CONTROLLED that certain desired properties are developed, heat-treating is accomplished. A material is heat-treated to improve it for the service intended, or to put it in a condition which will make a subsequent operation (such as machining) easier to perform.

Heat-treating is used for the following purposes:

1. To relieve stresses produced by forming or welding.
2. To increase hardness and tensile strength.
3. To develop ductility.
4. To induce toughness.
5. To aid machinability.
6. To increase wear-resistance.
7. To alter electrical properties.
8. To modify magnetic properties.
9. To develop a more desirable grain structure.
10. To change the chemical composition of a steel surface, as in case-hardening.

The particular treating process used depends upon the composition of the metal and the property you want to develop. Some processes not only cause changes in chemical and physical properties but alter the surface composition of the metal as well. When there is to be no change in composition, the heat-treating operation involves only heating and cooling, in which the factors of TIME and TEMPERATURE are most important. When there is to be a change in composition, the ELEMENT SURROUNDING the metal during heating, or during heating and cooling, is equally as important as time and tempera-

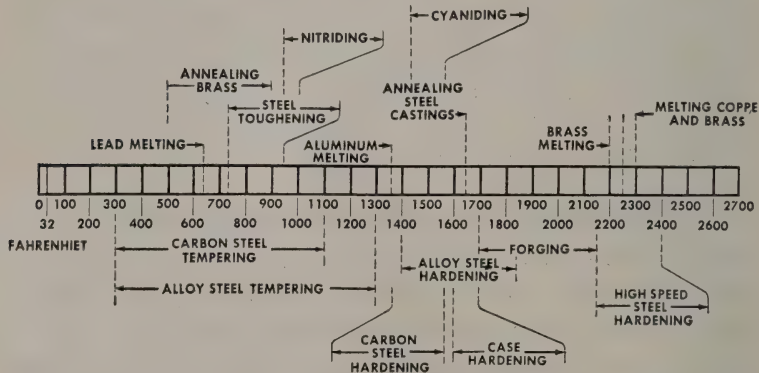


Figure 6–1.—Heat range chart.

ture. Those factors must be definitely fixed in advance for the composition of the metal and the treatment involved.

NORMALIZING, ANNEALING, HARDENING, and TEMPERING are methods of heat-treating which cause no change in the composition of the metal being treated. CARBURIZING, CYANIDING, and NITRIDING, on the other hand, are SURFACE- or CASE-HARDENING operations which DO effect a change in the composition of the metal near the surface. This change occurs because either carbon or nitrogen, or some combination of these two elements, is absorbed by the surface metal during the heat treatment. Case-hardening is used when a hard, wear-resistant surface on a tough ductile core is desired.

If you're a bit hazy about true heat-treating processes, you'd better square away those terms and processes by giving a good going-over to chapter 4, *Metalsmith 3 & 2*, NavPers 10565–A. You can get a good idea of the temperatures used for various heating operations from figure 6–1.

Effect of Alloying Elements

Addition of an element or elements to the composition of steel has a marked effect on the mechanical and physical properties of the steel, as well as on the manner in which it responds to heat treatment. Most of the elements added to a steel by the steelmaker are in the form of FERROALLOYS. In a ferroalloy, such as ferrosilicon, the element is already in combination with a certain percentage of iron.

Plain carbon steel has been made by man for 3,000 years. But it has only been during the past 50 years that alloying elements other than carbon have been added to augment the carbon. The addition of alloying elements enables a steel to do things that plain carbon steels cannot do.

There are four principal reasons why extra alloying elements are put into a steel. They are:

1. To obtain greater hardness for cutting or wear-resistance.
2. To greatly increase toughness and strength.

3. To accurately control size and shape of article during hardening.
4. To give a steel the PROPERTY OF RED-HARDNESS.

Analysis of typical SAE steel is shown in figure 6–2. You should be familiar with each element and its effect on steel. Effects of these various elements are summed up in the following paragraphs.

CARBON is present in all steels. It is necessary so that steel may harden. The ability of plain carbon steel to harden increases until about 0.80 percent carbon content is reached. Beyond that percentage the measurable hardness does not increase, but the wear-resistance does. The lowest plain carbon tool steel has 0.50 to 0.60 percent carbon; this steel is used for forging tools, hammer dies, and similar articles. The highest plain carbon steel has about 1.30 percent carbon; it is used for engraving tools.

Plain carbon steels must be cooled rapidly to harden. The hardened area beneath the surface is rather shallow. For example, a bar ¾ inch round, or larger, will harden only to a depth of $\frac{3}{32}$ or ⅛ inch. The remaining core of the bar will be tough but unhardened. Some other alloying element must be added to increase the hardness penetration.

MANGANESE, in a small quantity, is a necessary addition in all steels. It aids in carrying off sulfur and other impurities during manufacture. The presence of 0.20 percent manganese makes steel sound when first cast into ingots. It also makes steel easier to hot-roll and forge. A content greater than 0.50 percent must be present before the manganese is considered an alloy addition.

When 1.50 percent manganese is added to a steel containing 1.00 percent carbon, a powerful effect is produced. The manganese will cause a 2-inch cube to harden all the way through. Without the extra addition of manganese, a similar cube will harden to a depth of only $\frac{3}{32}$ in. below the surface.

Another effect of manganese additions is that the hardening speed of a steel is increased to a point where the steel will

NOMINAL CHEMICAL RANGES

S.A.E. No.	*Carbon Range*	*Manganese Range*	*Phosphorus Max.*	*Sulfur Max.*	*Silicon Range*	*Nickel Range*	*Chromium Range*	*Molyb. Range*	*Corres. AISI Number*
Carbon Steels									
*1016	0.13–0.18	0.60–0.90	0.040	0.050	....	....	....	....	C1016
*1022	0.18–0.23	0.70–1.00	0.040	0.050	....	....	....	....	C1022
1030	0.28–0.34	0.60–0.90	0.040	0.050	....	....	....	....	C1030
1055	0.50–0.60	0.60–0.90	0.040	0.050	....	....	....	....	C1050
1080	0.75–0.88	0.60–0.90	0.040	0.050	....	....	....	....	C1080
1095	0.90–1.05	0.30–0.50	0.040	0.050	....	....	....	....	C1095
Free Cutting Steels									
Open Hearth									
*1115	0.13–0.18	0.70–1.00	0.045	0.10–0.15	....	....	....	....	C1115
*1118	0.14–0.20	1.30–1.60	0.045	0.08–0.13	....	....	....	....	C1118
Manganese Steels									
1320	0.18–0.23	1.60–1.90	0.040	0.040	0.20–0.35	....	....	....	A1320
1340	0.38–0.43	1.60–1.90	0.040	0.040	0.20–0.35	....	....	....	A1340
Nickel Steels									
*2317	0.15–0.20	0.40–0.60	0.040	0.040	0.20–0.35	3.25–3.75	....	....	A2317
2330	0.28–0.33	0.60–0.80	0.040	0.040	0.20–0.35	3.25–3.75	....	....	A2330
2345	0.43–0.48	0.70–0.90	0.040	0.040	0.20–0.35	3.25–3.75	....	....	A2345
*2515	0.12–0.17	0.40–0.60	0.040	0.040	0.20–0.35	4.75–5.25	....	....	A2515

*Indicates carburizing grades of S.A.E. steels

Figure 6–2.—Analysis of typical SAE steels.

NORMAL CHEMICAL RANGES — Continued

S.A.E. No.	*Carbon Range*	*Manganese Range*	*Phosphorus Max.*	*Sulfur Max.*	*Silicon Range*	*Nickel Range*	*Chromium Range*	*Molyb. Range*	*Corres. AISI Number*
Nickel Chromium Steels									
*3120	0.17–0.22	0.60–0.80	0.040	0.040	0.20–0.35	1.10–1.40	0.55–0.75	....	A3120
3130	0.28–0.33	0.60–0.80	0.040	0.040	0.20–0.35	1.10–1.40	0.55–0.75	....	A3130
*3141	0.38–0.43	0.70–0.90	0.040	0.040	0.20–0.35	1.10–1.40	0.70–0.90	....	A3141
3150	0.48–0.53	0.70–0.90	0.040	0.040	0.20–0.35	1.10–1.40	0.70–0.90	....	A3150
3240	0.38–0.45	0.40–0.60	0.040	0.040	0.20–0.35	1.65–2.00	0.90–1.20	....	A3240
*3310	0.08–0.13	0.45–0.60	0.025	0.025	0.20–0.35	3.25–3.75	1.40–1.75	....	E3310
Molybdenum Steels									
*4027	0.25–0.30	0.70–0.90	0.040	0.040	0.20–0.35	....	....	0.20–0.30	A4027
4047	0.45–0.50	0.75–1.00	0.040	0.040	0.20–0.35	....	....	0.20–0.30	A4047
4130	0.28–0.33	0.40–0.60	0.040	0.040	0.20–0.35	....	0.80–1.10	0.15–0.25	A4130
4150	0.46–0.53	0.75–1.00	0.040	0.040	0.20–0.35	....	0.80–1.10	0.15–0.25	A4150
*4320	0.17–0.22	0.45–0.65	0.040	0.040	0.20–0.35	1.65–2.00	0.40–0.60	0.20–0.30	A4320
4340	0.38–0.43	0.60–0.80	0.040	0.040	0.20–0.35	1.65–2.00	0.70–0.90	0.20–0.30	A4340
*4620	0.17–0.22	0.45–0.65	0.040	0.040	0.20–0.35	1.65–2.00	....	0.20–0.30	A4620
4640	0.38–0.43	0.60–0.80	0.040	0.040	0.20–0.35	1.65–2.00	....	0.20–0.30	A4640
*4820	0.18–0.23	0.50–0.70	0.040	0.040	0.20–0.35	3.25–3.75	....	0.20–0.30	A4820

Chromium Steels									
*5120	0.17–0.22	0.70–0.90	0.040	0.040	0.20–0.35	....	0.70–0.90	....	A5120
5140	0.38–0.43	0.70–0.90	0.040	0.040	0.20–0.35	....	0.70–0.90	....	A5140
5150	0.48–0.55	0.70–0.90	0.040	0.040	0.20–0.35	....	0.70–0.90	....	A5150
52100	0.95–1.10	0.30–0.50	0.025	0.025	0.20–0.35	....	1.20–1.50	....	E52100
Chromium Vanadium Steel									
6150	0.48–0.55	0.65–0.90	0.040	0.040	0.20–0.35	....	0.80–1.10	Vanadium Min. 0.15	
Silicon Manganese Steel									
9260	0.55–0.65	0.70–0.90	0.040	0.040	1.80–2.20	....	....	....	A9260
Stainless Chromium Irons									
*51210	0.08–0.15	0.60	0.03	0.03	0.50	....	11.50–13.00	....	....
51335	0.25–0.40	0.60	0.03	0.03	0.50	....	12.00–14.00	....	....

*Indicates carburizing grades of S.A.E. steels

Figure 6-2.—Analysis of typical SAE steels.—Continued

crack if it is quenched in water. An example of this is a 0.90 percent carbon steel with 1.50 percent manganese added. A steel of this composition is an oil-hardening steel.

The critical point is slightly lower when manganese is alloyed in steel. Therefore, the temperature to which the steel is heated for hardening will be lowered.

SILICON additions in small amounts—0.10 to 0.30 percent—act in the same manner as manganese in facilitating the casting and hot-working of steel. Silicon, however, is never used alone or simply with carbon. Used with other alloying elements, it has tremendous power to add strength and toughness to steel. The usual amounts of silicon in tool steels range from 0.50 to 2.00 percent. When these amounts of silicon are present, it is necessary to exercise particular care to avoid overheating; otherwise, the steel is likely to decarburize during the forging and hardening process.

PHOSPHORUS and SULFUR in steel are usually considered impurities. Percentages of these two elements, therefore, are kept as low as possible. Tool steel in the cheaper grades usually is kept under 0.05 percent sulfur and phosphorus; in the better grades it is as low as 0.015 percent. In some grades of machinery steel, these two elements are deliberately added to aid in the free-machining of the steel. Since the products manufactured from this class of steel are not heat-treated in the same manner as tool steels, the sulfur and phosphorus content is of little importance.

CHROMIUM causes deeper hardness PENETRATION, but does not necessarily increase hardness. Present in large enough quantities, it greatly increases wear-resistance and toughness. The addition of chromium raises the temperature needed for hardening, whereas manganese lowers the temperature required for hardening.

Plain carbon-chromium steels containing from 0.25 to 1.50 percent chromium are used for reamers, knives, and twist drills. A carbon-chromium steel containing 4 percent chromium has mild red-hardness properties and is used for hot-forging dies. The high-carbon high-chromium steels—1.40 to 2.45 percent carbon and 11 to 14 percent chromium—

have remarkable wear-resistance properties. They are either oil-hardening or air-hardening and will retain their size and shape quite well when hardened.

About 4 percent chromium is used with tungsten and vanadium in high-speed steel. The behavior of the individual elements is difficult to determine when the alloy becomes complicated but chromium serves its normal purpose of increasing hardness penetration.

NICKEL has very little effect on the hardening of steel but, when used with chromium, it adds toughness and wear-resistance. With nickel present, the hardening temperature is lowered and the steel tends to be oil-hardening.

TUNGSTEN, to be effective, must be added in large amounts. About 4 percent with 1.30 percent carbon will make a steel so wear-resistant when hardened that the steel will be difficult to grind with an ordinary grinding wheel. This type of steel decarburizes quite readily because of the high temperature needed for hardening. The carbon-tungsten steel becomes very hard when quenched but, as with all carbon steels, the temper is drawn out when working conditions produce enough friction to generate heat above 630° F. A steel containing 18 percent tungsten, 4 percent chromium, 1 percent vanadium, and 0.70 percent carbon is known as HIGH-SPEED STEEL. This steel can continue cutting when the cutting edge has become a dull red—about 1,000° F.—and is the most important modern tool steel.

VANADIUM has a toughening effect on carbon steels when added in small quantities of about 0.15 percent. It prevents increased grain size when the metal is accidentally overheated. In small quantities, vanadium does not increase hardness or hardness penetration. When used with chromium and tungsten, however, it further increases red-hardness of high-speed steel. The lower percentage tungsten-chromium-vanadium alloy steels are used for hot-working dies.

MOLYBDENUM often replaces varying percentages of tungsten in high-speed steel. An example of this is the use of 7 percent to 10 percent molybdenum with chromium, vana-

dium, and tungsten. Molybdenum in small percentage increases toughness and wear-resistance in the same manner as tungsten, but it has a tendency toward greater decarburization during forging and heat-treating. Hardness penetration is increased with molybdenum and the steel tends to be oil-hardening.

Cobalt raises the temperature necessary for hardening, has a tendency toward surface decarburization, and decreases toughness. It is added to high-speed steel to increase red-hardness; thus, the speed of machining can be increased. High-speed steel is practically the only steel in which cobalt is used.

You cannot be sure what effect will be produced by the addition of a new element. Certain effects can be expected, but the steelmaker does not always know what properties will result from a new formula. A new formula must first be tested and tried. Two elements, when used in conjunction with each other, usually behave quite differently from the way in which each individual element behaves when used alone.

As a rule, the best steel to use is the one that will meet the requirements with the most simple analysis. As the number of elements and the quantity of the individual element increases, it becomes more difficult to keep the steel uniform and under accurate control.

Typical Heat Treatment

The addition of alloying elements in various amounts affects transformation temperatures. The range of transformation for any given steel is also affected by the rate or speed of heating and cooling as well as by the thickness of the piece you are treating. The critical point will also be affected by the grain size of the metal, because to transform a coarse-grained structure requires a higher degree of heat than is necessary to transform a fine-grained structure.

The first step is to locate the appropriate heating range for the metal to be treated. Heat-treating data are often

shown by diagram. A composite diagram of this type for five common alloys is shown in figure 6–3. For example, to determine the working critical point of a low nickel-chromium steel with a 0.5 percent carbon content, trace the vertical line representing 0.5 percent carbon content to point X, where it intersects the curved line representing the low nickel-chromium content. This intersection indicates the working critical point. In this case it is about 1430° F.

The table in figure 6–4 indicates the temperatures for treating various grades of SAE steels as recommended by the Society of Automotive Engineers.

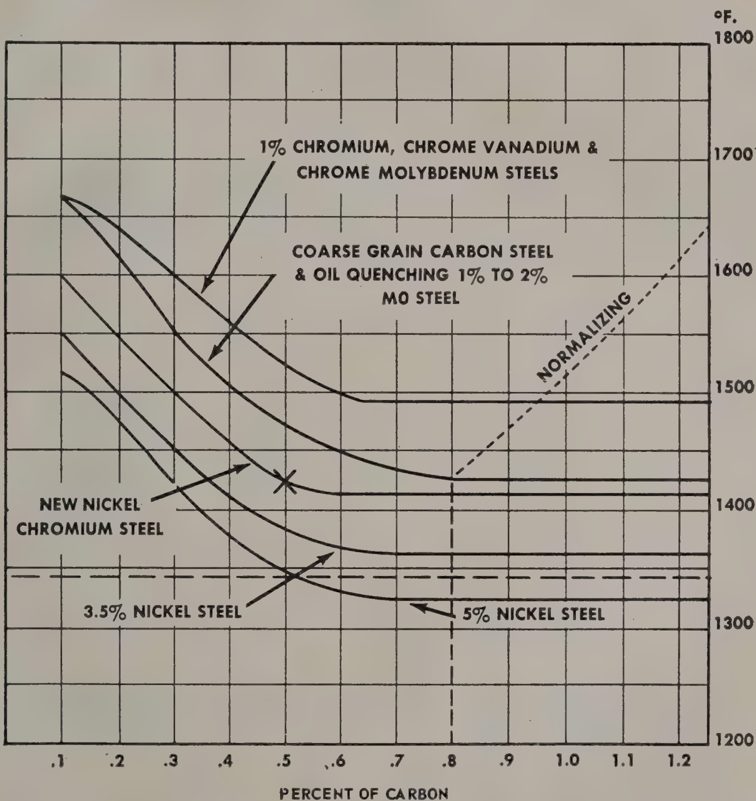


Figure 6–3.—Working range chart for carbon and low alloy steels.

272598°—54——13

HEAT TREATABLE S.A.E. TABLE

S.A.E. No.	*Normalize*	*Anneal*	*Hardening Temp., Deg. Fahr.*	*Quenching Medium*
Carbon Steels				
1030	....	....	1575–1650	Water
1055	1550–1650	1400–1500	1450–1550	Oil
1080	1550–1650	1400–1500	1450–1500	Oil
1095	....	1400–1500	1430–1500	Oil, water, or brine
Manganese Steels				
1330	1600–1700	1500–1600	1525–1575	Water or oil
1340	1600–1700	1500–1600	1525–1575	Oil
Nickel Steels				
2330	1600–1700	1400–1500	1450–1500	Oil
2345	1600–1700	1400–1500	1425–1475	Oil
Nickel-Chromium Steels				
3130	1600–1700	....	1500–1550	Water or oil
3141	1600–1700	1450–1550	1500–1550	Oil
3150	1600–1700	1400–1500	1500–1550	Oil
3240	1600–1700	1400–1500	1475–1525	Oil

Molybdenum Steels				
4047	Normalize	1450–1550	....	......
4130	1600–1700	1450–1550	1550–1650	Water or oil
4150	1600–1700	1450–1550	1500–1600	Oil
4340	1600–1700	1100–1300	1475–1525	Oil
4640	1600–1700	1450–1550	1450–1500	Oil
Chromium Steels				
5140	1600–1700	1450–1550	1500–1600	Oil
5150	1600–1700	1450–1550	1475–1525	Oil
52100	....	1350–1450	1425–1475 or 1500–1600	Water or oil
Chromium Vanadium Steel				
6150	1650–1750	1550–1650	1550–1650	Oil
Silicon-Manganese Steel				
9260	....	....	1500–1650	Oil
Stainless-Chromium Irons				
51210	....	1300–1350	1750–1825	Oil
51335	....	1425–1475	1800–1850	Oil or air
X51410	....	1300–1350	1750–1850	Oil

Figure 6–4.—Heat-treating data table.

Carbon tool steels used by the Navy are covered in Navy Department Specification 46S40b. The Navy classes for these steels are C1, C3, C4, C5, and C6. The carbon present in straight carbon tool steels ranges from about 0.71 to 1.10 percent. As the carbon content is increased, the transformation temperature decreases. When the carbon content is 1.10 percent, the hardening temperature is from 1,400° to 1,475° F. Lower carbon percentages require slightly higher hardening temperature. The hardening temperature for a 0.85 percent carbon tool steel is from 1,450° to 1,500° F. These plain carbon tool steels are quenched in brine or water and tempered at 300° to 500° F.

High-speed tool steels contain varying amounts of tungsten, cobalt, molybdenum, and vanadium. The Navy designates this class of tool steel the "T-class" and there are 12 steels of this class. The property of red-hardness varies according to the analysis of the steel.

Information pertaining to the analysis, use, and heat treatment of high-speed steels can be found in Navy Department Specification 46S37d. T-2 is the general-purpose steel of this class. The principal alloying elements in T-2 are about 0.80 to 0.86 percent carbon, 3.75 to 4.50 percent chromium, 1.90 to 2.30 percent vanadium, and 17.50 to 18.75 percent tungsten.

High-carbon, high-chromium tool steels hold their size and shape exceptionally well, without deformation. The carbon content of these steels varies from about 1.40 to 2.45 percent and the chromium from 11 to 14 percent. It is used for burnishing broaches, woodworking knives, shear blades, and lathe centers. This class of steel must be preheated to 1,500° F. before it is heated to the quenching temperature. The rate of heating for preheating and hardening must be slow and the stock must be held at the hardening temperature from 15 to 45 minutes. The hardening temperature will vary from 1,700° to 1,900° F., depending on the carbon content. The lower temperature is applicable to the higher carbon range. In this case, the steel is oil-hardening.

When the carbon content of high-carbon high-chromium steel is lowered, about 3.5 percent cobalt is added and the steel becomes air-hardening. High-carbon high-chromium steels are tempered as desired between 400° and 1,000° F. Some authorities believe it is undesirable to temper these steels between 600° and 800° F.

Manganese tool steels are often called nonshrinking oil-hardening tool steels. This steel does not hold to dimensions quite as well as the air-hardening high-carbon high-chromium steels. A typical analysis of manganese tool steel is 0.90 percent carbon, 1.10 percent manganese, 0.50 percent tungsten, 0.60 percent chromium, and 0.20 percent vanadium. This class of steel is preheated to 1,200° F., then slowly heated to the hardening temperature (about 1,450° F.), quenched in oil, and tempered between 325° and 500° F.

A good chisel steel is an alloy of 0.50 percent carbon, 2.00 percent tungsten, and 1.25 percent chromium. This stock is heated slowly to 1,400° F., then held at the hardening temperature (1,650° to 1,750° F.) for 10 to 30 minutes, quenched in oil, and tempered between 350° and 650° F.

Case-Hardening Procedures

A hard-wearing surface can be produced on a steel by heating it above its critical temperature and quenching the material in a cooling medium. But, to do this, the analysis of the steel must show sufficient carbon, or other alloying elements, to permit hardening. These hardening agents not only will be present at the surface where hardness is desired, but also will be found throughout the mass of the material.

When the steel is heated to its proper hardening temperature and quenched to get the desired surface hardness, the core or central portion of the piece will also undergo a change in properties and hardness with a resultant loss of toughness and ductility. This condition is not objectionable in some steels (depending upon their use) and subsequent tempering often restores toughness and ductility to a sufficient degree.

It is often desirable, however, to produce an article with

a core of MAXIMUM toughness and ductility and a surface with a high degree of hardness and wear-resistance. These conditions are met by selecting for the core a steel which has the desired toughness and ductility. The surface hardness is then procured by a treating process which changes the surface composition of the metal so that it will harden. This is accomplished by the addition of a hardening element—carbon or nitrogen, or a combination of the two—to the metal surface. The method by which the surface composition or analysis is changed and hardened is known as CASE HARDENING.

CARBURIZING, CYANIDING, and NITRIDING are the methods used to produce the case. Temperature, time, and material must be considered in each of these processes. The temperature to which the steel is heated must be high enough to permit rapid absorption of carbon or nitrogen. The absorption of carbon is not possible until a temperature is reached which transforms the iron of a steel, in a solid state, to gamma iron. Theoretically, gamma iron can absorb 1.7 percent carbon. In practice, however, the absorption of 1.2 percent is about the limit at the surface because the carbon MIGRATES toward the center of the core.

The LENGTH OF TIME that the piece is in contact with the element being added and held at the proper temperature will determine the DEPTH of the case. By regulating the time of exposure, the depth of the case can be controlled. The percentage of hardening element present in different parts of the case will vary. This is due to the migration of the hardening element from the surface into the body of the steel. The greatest thickness or depth of case obtainable in a case-hardening process is about 0.080 inch. Considerable time is required to produce a case of this thickness.

The MATERIAL from which the part to be case-hardened is made must be a steel that is suitable for the treatment decided upon or the treating method available in the shop. In the nitriding process, an alloy steel known as NITRALLOY must be used. An analysis of a typical nitriding steel is

0.38 to 0.43 percent carbon, 0.40 to 0.70 percent manganese, 1.40 to 1.80 percent chromium, 0.20 to 0.40 percent silicon, 0.30 to 0.45 percent molybdenum, 0.90 to 1.35 percent aluminum, and a maximum of 0.040 percent each of sulfur and phosphorus. The ALUMINUM content of these steels makes possible the absorption of nitrogen which, in turn, develops the surface hardness or case.

The SAE STEELS listed in figure 6–5 may be case-hardened by the cyaniding process, or by the pack or gas-carburizing method. The table also includes working temperature, cooling mediums, and tempering temperatures for each of the steels listed.

In some case-hardening processes, the operation is complete as soon as the article is removed from the action of the element surrounding it. In carburizing, not only does the surface composition have to be changed, but a subsequent heat-treating operation is also necessary to complete the case-hardening job.

CARBURIZING is the oldest of case-hardening procedures. This method of adding carbon to the surface of a steel can be accomplished by packing the article to be treated in a box containing carbonaceous materials, heating to the proper temperature to permit the absorption of carbon, holding at that temperature for the required length of time to obtain the desired depth of migration, and following by heat treatment to develop the hard-wearing case. This process is known as the PACK-HARDENING METHOD.

A modification of this method was developed in 1900; it is called GAS CARBURIZING. It consists of heating the steel above the critical range, in contact with carbonaceous gases. This method requires special carburizing machines and gas-cracking and gas-mixing devices, in addition to the usual quenching and tempering equipment. Most carburizing, however, is done by the pack-hardening method.

CYANIDING is the term applied to the case-hardening process in which steel, when heated to the proper temperature, absorbs a combination of nitrogen and carbon. POTASSIUM CYANIDE and FERROCYANIDE were the first compounds used.

CARBURIZING GRADES

S.A.E. No.	*Carburizing Temp., Deg. Fahr.*	*Cooling Method*	*Reheat, Deg. Fahr.*	*Cooling Medium*	*2nd Reheat, Deg. Fahr.*	*Cooling Medium*	*Temp., Deg. Fahr.*
Carbon Steels							
1015	1650–1700	Oil or Water	1400–1450	Water or Brine	....	....	250–325
1020	1650–1700	Cool slowly	1650–1700	Oil or Water	1400–1450	Water or Brine	250–325
Free Cutting Steels							
1115	1650–1700	Oil or Water	1400–1450	Oil or Water	....	....	250–325
1118	1650-1700	Cool slowly	1650-1700	Oil or Water	1400-1450	Water or Brine	250-325
Manganese Steel							
1320	1650–1700	Cool slowly	1525–1575	Oil	1375–1425	Oil	250–300
Nickel Steels							
2317	1650–1700	Cool slowly	1500–1550	Oil	1350–1400	Oil	250–300
2515	1650–1700	Cool in box	1500–1550	Oil	1325–1375	Oil	250–400

CARBURIZING GRADES — Continued

S.A.E. No.	*Carburizing Temp., Deg. Fahr.*	*Cooling Method*	*Reheat, Deg. Fahr.*	*Cooling Medium*	*2nd Reheat, Deg. Fahr.*	*Cooling Medium*	*Temp., Deg. Fahr.*
Nickel-Chromium Steels							
3120	1650–1700	Cool slowly	1525–1575	Oil	1375–1425	Oil	250–300
3310	1650–1700	Cool slowly	1525–1575	Oil	1375–1425	Oil	250–300
Molybdenum Steels							
4027	1650–1700	Quench in Oil	....	....	....	....	250–300
4320	1650–1700	Cool slowly	1425–1475	Oil	....	....	250–300
4620	1650–1700	Cool slowly	1525–1575	Oil	1375–1425	Oil	250–300
4820	1650–1700	Cool slowly	1550–1650	Oil	1350–1400	Oil	250–300
Chromium Steels							
5120	1650–1700	Cool slowly	1600–1650	Oil	1425–1475	Oil	250–300

Figure 6–5.—Carburizing data table.

The cyanide compound now used is a mixture of SODIUM CYANIDE and SODIUM CHLORIDE. This compound is covered in JAN–C–1141. It gives best results when used in a bath.

The general procedure is to melt the cyanide bath, insert the pieces to be treated, slowly heat to the cyaniding temperature (1,450° to 1,550° F.), and hold at that temperature for a specific length of time. The length of time the piece is immersed at the proper temperature will determine the thickness or depth of the case.

The case is produced by quenching the article in water or oil which is then agitated. The oil used as the quenching medium must be a high-grade mineral oil; other types of oil produce a soapy substance which retards cooling of the part.

The advantage of cyaniding is the ease with which the case is produced. Elaborate treating equipment is not required, although electric cyaniding bath furnaces are frequently used in production shops. Small parts can be case-hardened quickly with the cyaniding process because a shallow depth of hardness is all that is required.

The case depth produced on an SAE 1020 steel, immersed for 1 hour at 1,550° F. and water quenched, is 0.010 in. The same steel immersed for 3 hours will have a case depth of 0.018 in. The composition of the steel has an effect on the case thickness. For example, the case that can be produced on an SAE 2315 steel, which is a low-alloy steel, is slightly greater. After 1 hour of immersion at 1,550° F., this steel will have a case 0.012 in. thick. As in pack carburizing, slow and uniform heating is recommended for cyaniding procedures.

NITRIDING is a case-hardening process that has been developed in recent years. This method can be used only with special nitralloy steels, which are designed to absorb nitrogen. Elaborate treating equipment is required and the process is more expensive than carburizing or cyaniding.

The low temperatures—950° to 1,000° F.—required for nitrogen absorption, and the fact that a quench is not necessary to produce the case, permit the development of a hard

surface on finely machined articles without danger of warping or the development of thermal stresses.

Case-hardening by the nitriding process is accomplished by subjecting the article to the proper temperature in the presence of AMMONIA for a specified period of time. The nitriding furnace must be tightly sealed. Ammonia is admitted to the furnace chamber, displacing all the air. The furnace is then slowly heated to the nitriding temperature. An even temperature and a continuous flow of the nitriding gas must be maintained throughout the operation. As the ammonia decomposes, nitrogen is absorbed by the steel, producing the hard case.

Relation of Design to Heat Treatment

PROPER TOOL DESIGN, from the standpoint of heat treatment, may be considered satisfactory if, during heat-treatment, the entire piece can be heated and cooled at approximately the same rate in all parts. When the difference in temperature between various parts is excessive during quenching, stresses and strains are set up. When the stresses are greater than the strength of the material, the tool will crack during the treating operation. Even if the part does not crack during the treatment, the stresses may be great enough to cause failure in service under light loads.

Sharp corners and excessive difference in the thickness of various parts of a tool must be avoided. These two points must be considered by the designer if the tool is to be successfully heat-treated.

Figure 6–6 illustrates the manner in which sharp corners and differences in the thickness of parts can be eliminated or modified by rounding off angles (6–6 A and B), where possible, and by drilling or machining out part of the heavy section (6–6C).

RESURFACING

Building Up With Bronze

Surfaces of worn parts of many machines and tools can be BUILT UP WITH BRONZE. This method is used to restore the

efficiency of pistons, guides, shafts, and other parts. Bronze should not, however, be used if the working temperature of the built-up surface exceeds 500° F.

Steel parts to be bronze-surfaced should be thoroughly cleaned by machining, grinding, chipping, or sandblasting. Cast iron parts should NOT be machined, but they may be cleaned by the other methods. If cast iron parts are machined, they are difficult to "tin" with bronze and a good bond cannot be established.

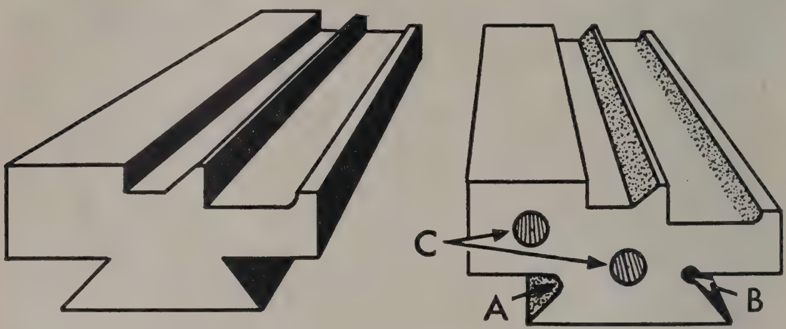


Figure 6–6.—Incorrect and corrected design of an undercutting form-tool.

Alloy, used for filler metal or build-up metal, is usually known as bronze. But it's really a BRASS containing about 60 percent copper and 40 percent zinc. Certain bronzes, including phosphor-bronze, may be used to give special properties and characteristics to the weld-metal deposit. Some of these alloys are designed to resist abrasion, others to resist high temperatures, and still others to have high ductility. All of the bronze build-up alloys are readily machinable. Most of them have a melting point of about 1,600° F.

The build-up of a 20-inch steel piston is shown, step by step, in figure 6–7. The rough-turned grooves are filled first, then the surface is built up with one, two, or three layers of bronze, as required.

Steel parts subjected to heavy stresses and strains should be built up or resurfaced only once. Cast iron may be resurfaced as often as necessary.

When a layer of bronze is applied, it must be kept THIN—under 1/8 inch—and well-bonded to the "tinned surface" or preceding layer. Preheating and a good brazing flux are necessary for good bonding and tinning and for the clean deposition of metal.

AVOID OVERHEATING—it will prevent proper tinning and bonding and may damage both the base metal and the filler metal.

When resurfacing with bronze or brass, two important safety precautions must be observed:

1. CORED OR OTHERWISE ENCLOSED SPACES MUST BE VENTED.—If not vented, they will vent themselves in a drastic manner—by a terrific EXPLOSION. Remove vent plugs, or drill small holes through which expanding gases may escape when the part is heated.
2. DON'T BREATHE ZINC FUMES.—Provide plenty of ventilation when working with brasses and bronzes because they contain up to 45 percent zinc. Wear a respirator if you do much welding and brazing of zinc-content alloys. Drink plenty of MILK—it's a good antidote for zinc poisoning.

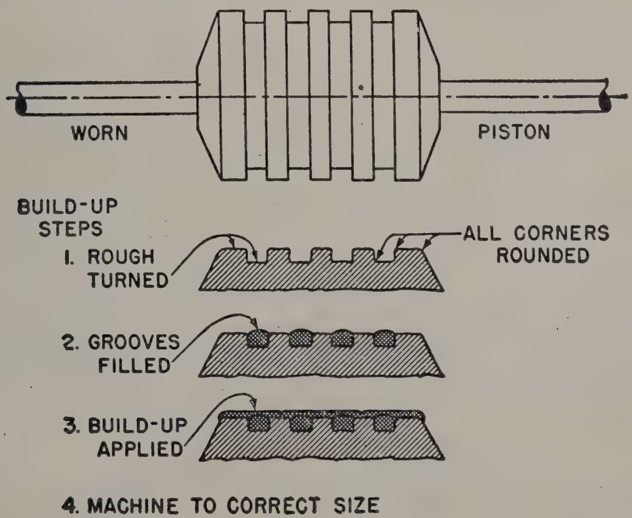


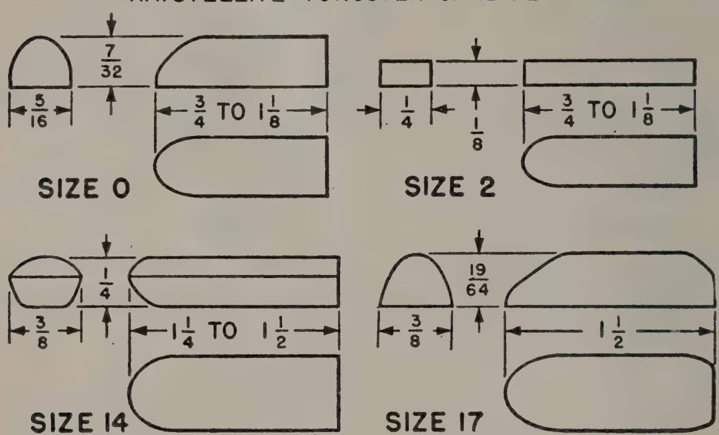
Figure 6–7.—Bronze surfacing of a steel piston.

Saving the Surface

Working surfaces of many metal objects—such as cutting tools, machine tools, machine parts, valve facings, etc.—wear away and lose their usefulness. The wear is caused by FRICTION (ABRASION) or is the result of IMPACT (blows). Such worn parts may be resurfaced with special abrasion-resistant and shock-resistant alloys.

The process of resurfacing is called either HARD-FACING or HARD-SURFACING. Even new parts are sometimes surfaced or resurfaced when they are manufactured.

HAYSTELLITE TUNGSTEN CARBIDE INSERTS



MANY OTHER SIZES AND SHAPES ARE AVAILABLE

Figure 6–8.—Tungsten carbide hard-facing inserts.

Hard-surfacing material is usually so applied that it forms a THIN LAYER over the base metal. The thickness of the deposit is usually from $1/16$ to $1/8$ inch, but seldom over $1/4$ inch. Applications on small parts ordinarily are made with an oxyacetylene torch. Some hard-surfacing alloys are also available in the form of electrodes for metal arc welding. All these alloys are highly resistant to corrosion.

Materials for Hard-Facing

There are three general types of hard-facing materials. IRON-BASE ALLOYS, which contain nickel, chromium, man-

ganese, and other hardening elements, come in rod form and are fused to the base metal by welding. They melt at about the same temperature as steel.

TUNGSTEN or COBALT alloys are also furnished in rod form. They are sweated to the base metal by a process similar to that used for bronze-welding.

TUNGSTEN CARBIDE is furnished in the form of small cast inserts (see fig. 6–8). The inserts are not melted but are held in place by weld metal built up around them. This is the hardest facing material—almost as hard as a diamond.

ALLOYS used for hard-facing are manufactured under many trade names, such as Stellite, Colmonoy, Blackor, Manganal, Borod, Carboloy, Haschrome, and Stoodite. In figure 6–9, the hard-facing products made by two different companies are compared and arranged into five groups according to characteristics and use.

Haynes stellite (group 3) is used extensively and is available in THREE standard grades, as follows:

1. GRADE No. 1 is extremely hard and has the greatest wear-resistance. It's so hard it may chip or crack if subjected to extreme pressure or heavy shocks.
2. GRADE No. 12 is softer than No. 1 and less resistant to abrasion. However, it is stronger, tougher, more ductible, and more resistant to shock or impact.
3. GRADE No. 6 is stronger than either No. 1 or No. 12. While its abrasion-resistance is somewhat lower, No. 6 does not crack easily from shock or impact. It's better able to stand up under sudden temperature changes. That's why it's used for valve facings on high-pressure, high-temperature steam lines.

The Navy Department Specification No. 46R5 hard-facing rod is the standard material for application to high-pressure high-temperature valve seats and disks. It's also used to face engine exhaust valve seats, disks, and other valves.

Metals Which Can Be Hard-Surfaced

Low-carbon and medium-carbon steels and low-alloy steels are easily hard-surfaced by either the torch or arc method.

HARD-FACING MATERIALS			
Group	Stoody Products	Haynes Products	Characteristics and Uses
1	STOODEX STOODY SELF-HARDENING	HASCHROME	Iron base. 50% to 80% iron, 20% or more of alloying agents. Used where toughness and shock resistance are important. May be used as base for other hard-facing alloys.
2	STOODY SELF-HARDENING STOODITE	HASCHROME	Similar to group 1 but harder and less resistant to shock though more resistant to abrasion.
3	SILFRAM STOODITE	STELLITE	Non-ferrous alloys of chromium, tungsten, cobalt and other non-ferrous metals. Available in several grades for a wide variety of application.
4	BORIUM COBALT BORIUM	HAYSTELLITE	These are diamond substitutes. Extremely hard and wear resistant. They are made of almost pure tungsten carbide. Furnished in the form of small cast inserts. High melting temperature—well above that of steel.
5	TUBE BORIUM BOROD	HAYSTELLITE	Similar to group 4 but furnished in the form of crushed particles or powder. Particles are contained in tube or imbedded in steel rods. Particles do not melt but are held in place by surrounding weld metal.

Figure 6–9.—Hard-facing alloys arranged by groups.

High-carbon steels can be faced if they are first annealed. They must be heat-treated after they've been hard-faced. Minimum penetration is advisable.

It is NOT advisable to attempt to hard-face a high-speed steel because the heat required for application damages the base metal. Corrosion-resisting steels and Monel metal are easily hard-faced by either the oxyacetylene or the arc process. Corrosion-resisting steels must be heated and cooled uniformly to avoid warping and cracking.

Cast iron—gray and alloy—may be hard-faced by either the gas or arc method. Care must be taken on thin edges, however, because the melting point of cast iron is somewhat below that of steel.

Malleable iron is seldom faced because the heat required for hard-facing will cause the base metal to become harder and more brittle.

Brasses and bronzes are difficult to hard-face because their melting points are considerably below those of the hard-facing alloys. Limited applications are possible with the metal-arc method.

Aluminum and aluminum alloys CANNOT be hard-faced.

Preparation of Base Metal

Metal surfaces to be hard-faced should be cleaned of all dirt, scale, and rust by grinding, machining, or chipping. In a pinch, it is permissible to file, wire brush, or sandblast, but the other methods produce best results.

Edges of grooves, corners, or recesses must be well rounded to prevent overheating of the base metal, and to provide a good cushion for the hard-facing material.

When PREHEATING is required for hard-facing, it is done in the same manner as for fusion welding. If preheating is necessary for good welding, that's a cue to preheat for hard-facing.

After a piece of steel is hard-faced, it should be heated to its critical temperature and quenched IN OIL. Don't quench in water, because cooling the steel too rapidly will crack the layer of hard-facing material.

Hard-Facing With the Torch

Use of the oxyacetylene flame allows CLOSE CONTROL of the hard-facing operation and produces smooth deposit. Scale and foreign matter are easily eliminated by this method, and edges and corners are readily formed. This is important when the hard-facing must be finished (ground) to close limits.

Degree of PENETRATION can be accurately controlled with the flame method. This is important because some facing alloys must be fused and puddled into the base metal, while others are merely sweated onto it.

The torch-tip size for hard-facing should be about two

sizes larger than that used for welding with a welding rod of the same size.

Now, take another look at figure 6–9, and notice how the process of hard-facing with a torch varies according to the characteristics of the five different groups of facing products.

For the products in group 1, the flame should be CARBURIZING. This increases the hardness of the deposit. You should puddle the hard-facing rod into the base metal just enough to secure good fusion. For greatest hardness, cool slowly after application. For a softer but tougher facing, quench in oil when the temperature is just below the melting point.

Group 2 can be handled in a manner similar to group 1, except that deeper penetration and more puddling are permissible. The acetylene feather or streamer should be two or three times the length of the inner cone of the flame.

The alloys in group 3 are nonferrous and are applied by SWEATING. The surface of the base metal (steel) should not be melted at all. Do not stir or puddle the rod. Control the thickness of the deposited metal by manipulation of the flame. Only a small area should be faced at one time.

Group 4 alloys are of the insert type and should NOT be melted. The process for using them is sometimes called "hard-setting." To apply an insert, first stick it to the molten end of a high-test steel welding rod. Melt the base metal and push the preheated insert into place. Then surround and cover the insert with the steel which is melted from the high-test rod. Repeat the process for each insert.

Crushed tungsten carbide is used to make the alloys in group 5. As explained in figure 6–9, particles are imbedded in steel strips or rods, or used to fill steel tubes. For application, the surface of the base metal should be melted and the hard-facing rod stirred to distribute the crushed particles in the deposited metal.

Hard-Facing With the Arc

Hard-facing alloys of groups 1, 2, and 3 may be applied with the arc if REVERSED POLARITY is used. Coated electrodes

are the general rule with this process. They reduce spatter loss, assure good penetration, prevent oxidation of the deposited metal, and help to stabilize the arc.

The arc is kept as long as possible; the voltage, as high as possible. The following table can be used as a general guide for current settings:

Size of electrode	*Current (amps)*
1/8 inch	100 to 150
3/16 inch	150 to 200
1/4 inch	200 to 250

Group 4 and group 5 hard-facing alloys may be "set on" with heat provided by a carbon arc. Set the welding machine for STRAIGHT polarity. The process is much the same as for oxyacetylene torch application of the same materials.

Finishing by Grinding

Hard-facing deposits are so hard they cannot be filed or machined. They must be ground to size and shape. Because of their extreme hardness, they should be built up only slightly larger than the exact size, thus eliminating unnecessary grinding.

Use a soft grade, vitrified bonded, 46- to 60-grit wheel for grinding hard-facing deposits. The SURFACE SPEED of the wheel should be from 2,800 to 4,200 surface feet per minute. Remember—don't confuse surface speed with revolutions per minute.

Practical Applications

You may be called on to state details and specifications in a subjob order for applying hard-facing alloys to lathe centers, lathe cutting tools, shaper tools, hand-snip blades, shear blades, gate-valve and globe-valve facings, engine valves and seat rings, and many other parts and tools.

Lathe and shaper tools may be hard-faced by the method shown in figure 6–10. The hard-facing alloy to be used will be determined by the kind of alloys available and by the expected use of the tool.

Some lathe tools are made of ordinary mild steel and then faced with high-speed tool steel. The mild steel provides

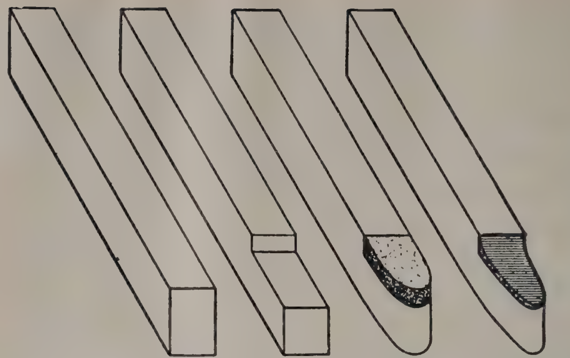


Figure 6–10.—Hard-facing a lathe cutting tool.

a tough shock-resistant backing for the more brittle tool-steel edge.

Worn gate-valve wedges may be resurfaced with hard-facing alloys. The faces of the wedge should be machined to the shape shown as step 1 in figure 6–11. Notice how the edges and corners are rounded before the hard-facing alloy is applied.

Gate-valve seat rings are hard-faced by the method shown

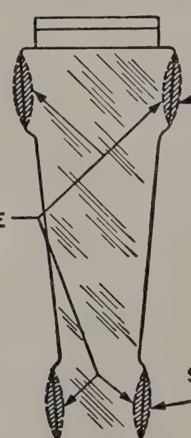


Figure 6–11.—Hard-facing a gate-valve wedge.

in the cross-sectional views of figure 6–12. Such jobs must be dressed or finished by grinding.

Other Uses of the Oxyacetylene Flame

The oxyacetylene flame is a most useful and adaptable tool. In addition to its use in welding, cutting, building up with bronze, and hard-facing, it may be used for many other jobs. Some of these jobs are hardening, softening, straightening, strengthening, descaling, machining, planing, and dehydrating.

Use of the oxyacetylene flame for hardening or softening is merely substituting the welding torch for the furnace and doing a bit of heat-treating.

Flame-hardening uses the oxyacetylene flame merely as a heating source and no carbon is added to the surface. The depth of hardness is no greater than the heat penetration in a steel capable of hardening. Flame-hardening can be used to harden the surface of heavier sections, or to harden the entire thickness of lighter sections, and thus improve the wearing qualities of the steel. For steels whose carbon content is 0.40 percent or higher, the process consists of heating to the critical temperature and quenching in water. Steels containing 0.70 percent carbon or higher can be handled in the same manner except that the heated parts must be cooled less rapidly. Compressed air or a spray of compressed air and water are used for quenching such steels. For steels of less than 0.40 percent carbon, the oxyacetylene flame can be adjusted to a high carburizing flame to introduce carbon into the surface of the steel. This particular application of the flame is similar to case-hardening.

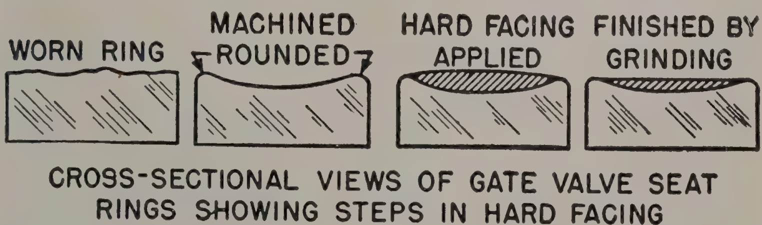


Figure 6–12.—Hard-facing a valve seat ring.

Flame-softening is done with the oxyacetylene flame adjusted to neutral. This process is especially adaptable for use on air-hardening steels, particularly when only small areas of large objects are to be treated. Flame-softening is often used after cutting structural steels and other low alloy steels that become hard and brittle on being rapidly air-cooled from a red-hot condition. The flame is adjusted to neutral and moved slowly across the area to be softened; then the heated portion is allowed to cool slowly. In this way, the original softness of the metal will be restored.

Flame-straightening is often desirable for restoring a shaft or similar part to its original alignment. Steel parts, which because of uneven heat have expanded and thereby been distorted, can be returned to their original shape. This process sometimes is referred to as spot-heating.

Flame-strengthening is accomplished with the oxyacetylene flame by the same principle as that used for flame-hardening. It can be used in certain special cases to strengthen pieces which have been affected by the heat of a welding flame. When a piece is machined with sharp corners or fillets, or when there are severe changes in section, flame-strengthening can be used to advantage to remove the stresses set up at sharp corners. The part to be stress-relieved is heated up to the hardening temperature and quenched with water, water-air mixture, or with air—depending upon the composition of the steel being treated.

Flame-descaling may be used to remove rust, scale, or other surface irregularities. This is done by passing the high temperature flame over the surface and causing the scale or rust to expand rapidly and flake off.

Flame-machining is used on steel to remove surface defects—such as cracks, seams, pits, or defective sections of welds. In this operation, a cutting torch, operating at low oxygen pressure, is held at an angle to the steel surface and moved slowly over the surface of the defective section. The surface is grooved by this process and can be rewelded to restore the desired surface dimensions. Defects in welds or in the steel plate show up in the reaction zone in the form of

bright spots or lines. The slag produced by the cutting is washed up out of the groove by the flame and can be removed from the surface by wire brushing or grinding.

Flame-planing is another of the applications of the oxyacetylene flame. It consists in the removal of wide and relatively shallow surface cuts from steel sections which are to be further rolled or machined. The process is performed in much the same manner as flame-machining, except that a cutting tip with a specially designed orifice is used.

Flame-dehydrating is used to advantage if there is a heavily rusted or scaled surface to be prepared for painting. The intense localized heat causes the heavier flakes of scale to flake off and the more adherent scale is loosened when the moisture it contains changes into steam. The rust and scale are then removed by wire brushing. To get the best job, the painting should be done while the surface is still warm to the hand (see fig. 6–13).

METALIZING

Metalizing is a rapid and effective method of applying practically any metal to a base material by spraying with a gun, thus aiding in restoring worn mechanical equipment

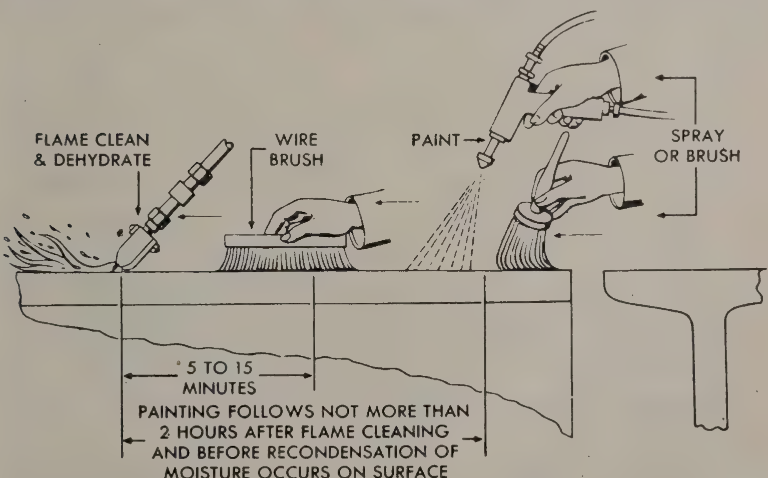


Figure 6–13.—Operations and time intervals in flame-cleaning and flame-dehydrating.

to service, salvaging mismachined or other defective parts, and protecting metals against corrosion. The metalizing process provides Navy shipyards and repair ships with a means of coating metallic and nonmetallic surfaces with practically any metal or alloy that can be made in rod or wire form.

In the metalizing technique, three essential phases are involved: (1) the careful preparation of the surface to receive the metal spray, (2) application of the metallic coating by spraying with a specially built spray gun, and (3) the final finishing of the sprayed surface in accordance with certain recommended procedures.

Preparation of Surfaces for Metalizing

In order to ensure a good bond between the sprayed coating and the base material to which it is applied, the base material must be roughened and must be free of oxides, oil, water, etc.

Undercutting is almost always necessary when building up shafts, bearing surfaces, rolls, etc., both in order to have the correct thickness of sprayed metal on the finished job, and in order to properly dovetail or key the ends of the coating. Figure 6–14 illustrates the correct undercutting of a shaft.

Since all sprayed metal has a low tensile strength, the sprayed metal should be keyed or dovetailed into ends of the

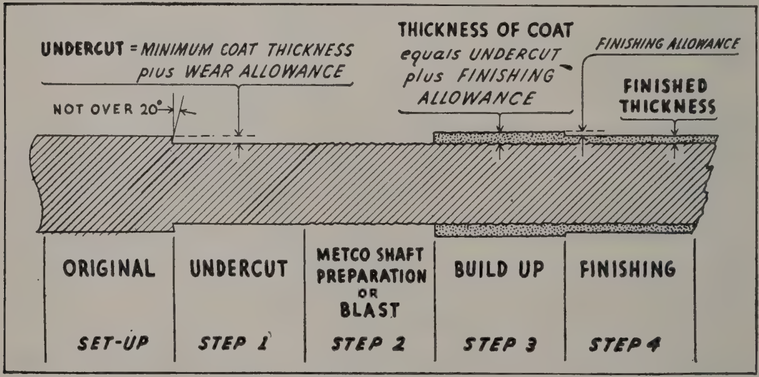


Figure 6–14.—Undercutting.

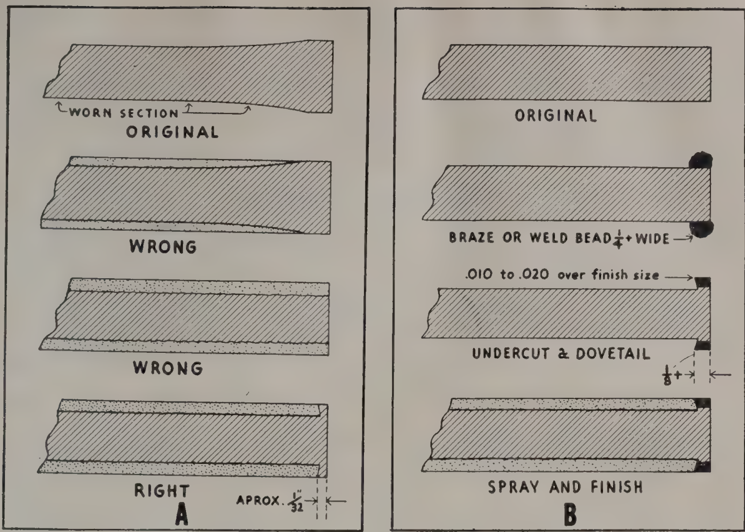


Figure 6–15.—Dovetailing.

base material. The coating should never be allowed to taper off to a feather edge. (See A of fig. 6–15.)

If the worn section of the shaft extends to the end of the shaft so that it is impossible to dovetail the cutting, it may be necessary to braze or weld a bead around the end and cut a dovetail in the brazed or welded metal, as illustrated in B of figure 6–15.

Still another method of preparing shafts for spraying has been developed. This method employs the lathe and a special rotary shaft preparing tool, as follows: First, groove the shaft in a lathe with a tool bit, ground as shown in figure 6–16. A standard 1/8-in. cut-off tool blade, ground on the side to give a thickness of from 0.045 in. to 0.050 in. and rounded on the end, makes a good tool for this purpose. The rake and clearance should be standard for the material of the shaft, to give a good cut. The grooves should be cut 0.025 in. deep and may be made either by using the lathe lead screw, or by simply cutting a number of separate grooves.

Second, the special rotary shaft preparing tool is mounted in the lathe tool post, and is then run back and forth over

the shaft to roughen the surface on top of the ridges; this roughens and spreads the ridges, forming dovetail grooves. It is very important that all turning be dry and that the shaft be kept free from oil and grease. Figure 6–17 illustrates proper grooving technique.

Spraying Technique

Many types of work have peculiarities which make it necessary to vary the method of spraying to obtain the desired results. While it is not possible to outline the correct procedure for every job, the following general considerations will prove helpful. You will "get the feel" of the gun and almost instinctively know and follow the right procedure after a reasonable amount of practice.

The SPRAY GUN is simply an oxyacetylene torch with a compressed air motor to feed the wire through the gun to the melting point of the flame. Figure 6–18 illustrates the spray gun.

When a shaft is to be sprayed, it should be mounted on centers in a lathe or other turning device. The gun is then

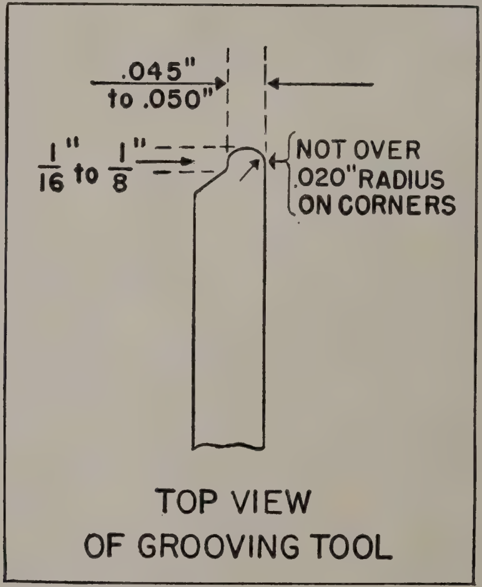


Figure 6–16.—Grooving tool.

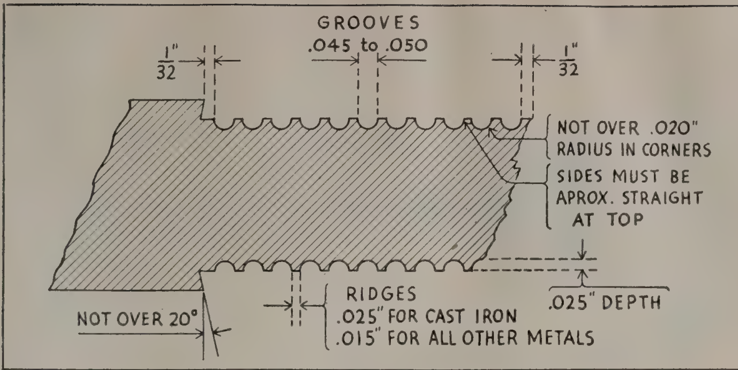


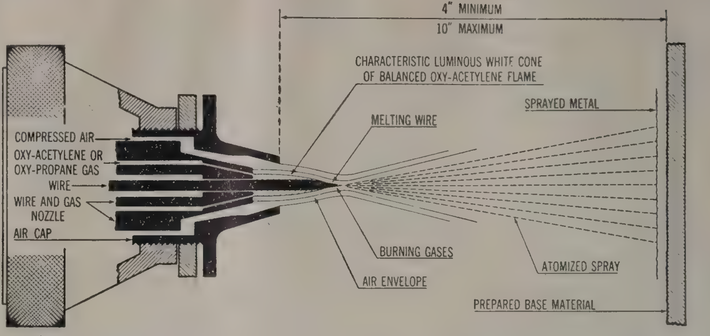
Figure 6–17.—Grooving the base material.

mounted in the tool post, with the nozzle of the gun about 5 or 6 inches from the surface of the work.

Pieces with diameters of 2 inches or under should be turned at the rpm that will give a surface speed of about 35 fpm, while the carriage feed should be set at about 1/8 in. per revolution. Pieces with diameters over 2 inches should be turned at the rpm that will give a surface speed of about 50 fpm, while the carriage feed should be set at about 1/16 in. per revolution. It is not necessary, of course, to adhere rigidly to these settings. If the surface speed is increased, or the carriage feed made faster, the result will simply be that each pass will apply a lighter coat of sprayed metal. If the surface speed is decreased or the carriage speed made slower, the result will be a heavier coating of sprayed material. Only a slight variation from the recommended speeds and feeds will be necessary for most jobs.

When SPRAYING INSIDE DIAMETERS, the same general rules apply as given for shafts. The only exception is that the coating should never be applied with one pass of the gun. The rpm should be set to give a surface speed of about 75 fpm, and the carriage or traverse speed should be set at 1/16 in. per revolution.

In SPRAYING FLAT SURFACES, skill is required of the operator if an even coating is to be obtained. For example, passing



WIRE NOZZLE AND AIR CAP CROSS SECTION - METCO METALLIZING GUN

Figure 6–18.—The spray gun.

the gun across the surface with the same speed for all metals that are used will result in applying a light coating of metals which spray slowly, and heavier coatings of the faster spraying metals. Here again, experience will teach the correct speeds for passing the gun over the surface. There is, however, a tendency to apply too heavy coatings of the faster spraying metals.

To SECURE AND MAINTAIN MAXIMUM SPRAYING SPEEDS, the best procedure is as follows:

1. Always set the regulators at specified pressures and light the gun as specified in the manufacturer's instruction book.
2. Slowly increase the speed of the wire until the gun is spattering rather than atomizing.
3. Slowly raise and lower the oxygen pressure while watching the melting end of the wire. Attempt, by changing pressure, to secure good atomization which will result in the wire melting closer to the end of the air cap.
4. If, after the oxygen has been adjusted, the wire is still spattering, slow the wire feed only to a point where the spattering ceases.

On the other hand, if the oxygen adjustment results in the wire melting back with (or close to) the end of the air cap,

the wire speed should be increased to the spattering point and then slightly retarded as before.

5. While spraying, pay close attention to the flame and the melting edge of the wire. If small blue streamers of flame appear, acetylene pressure has become too high, and oxygen pressure should be raised slowly until the blue streamers disappear. If the flame becomes smaller and the wire appears to speed up and run out of the flame, oxygen pressure is too high and should be lowered slowly until the atomization is again normal.

Finishing Sprayed Metal

The structure of sprayed metal deposits is granular rather than homogeneous. This structure, by its relatively low coefficient of friction and its oil-retaining properties, makes sprayed metal ideal for all bearing surfaces, but creates a problem in finishing.

When lathe finishing sprayed metal, you cannot use the same feeds, speeds, or tool bit shapes or settings which you would use on similar metal in its solid form, since this would result in crumbly chips similar to those from cast iron, and the surface would appear to be full of "pin pricks." Likewise, when grinding sprayed metal it is necessary to use different grain size, grade, bond, speeds, and feeds than you would customarily use. The use of customary grinding procedures would result in a spiralled and discolored surface, regardless of the manner in which the wheel is dressed.

The use of CARBOLOY TOOLS simplifies to a considerable extent the machining of sprayed metal, and affords better finishes than can be obtained with alloy steel tools. Since Carboloy has a very low friction coefficient and high resistance to welding, it will cut freely with much less rake and clearance than ordinary tool steel, and better finishes will result. Also, when Carboloy is used, the setting of the tool is less critical; in most cases, the tool may be set directly on center for the rough cut and, if necessary, raised slightly above center for the finish cut. Figure 6–19 illustrates tool

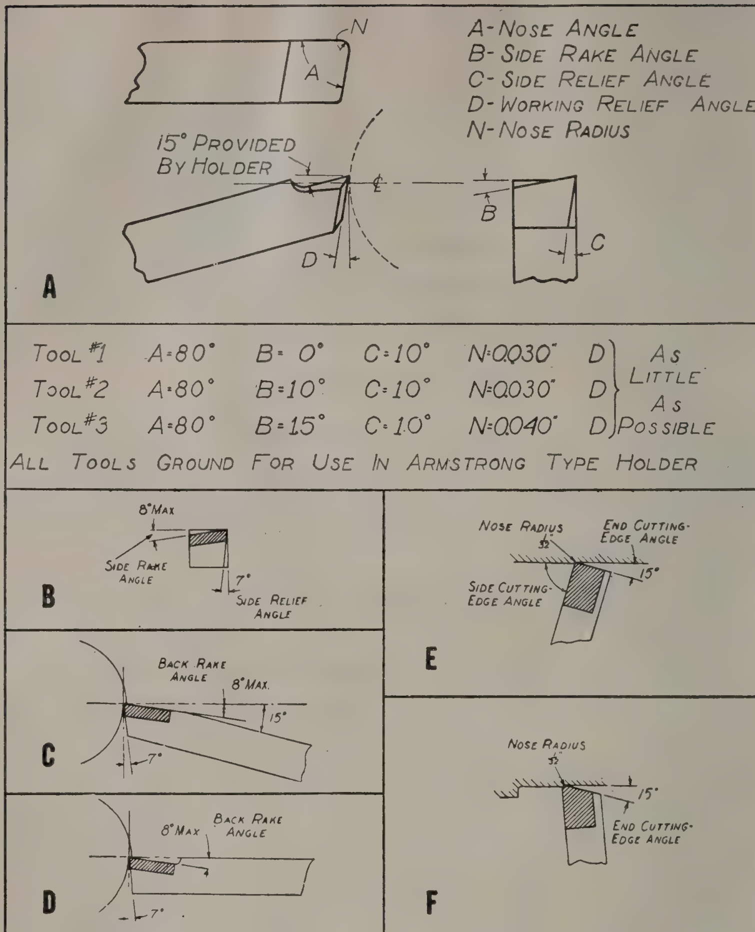


Figure 6–19.—Correct tool bit angles.

bits ground at angles recommended for machining sprayed metals.

Wet grinding of sprayed metal is preferable to dry grinding and should be used whenever suitable equipment is available. It presents no difficulties, provided the right wheels are used at recommended speeds and feeds.

In the past, considerable difficulty has been experienced due to the lack of accurate information as to grinding pro-

cedure and wheels, and also because most machine operators are inclined to disregard the all-important fact that sprayed metal calls for different wheels and procedures. All sprayed metals tend to "load" a wheel. Consequently, for grinding sprayed metal, a wheel of relatively coarse grain and low bond strength is necessary. Figure 6–20 shows the recommended wheels, speeds, and feeds for wet grinding of the various sprayed metals.

TABLE III - WET GRINDING RECOMMENDATIONS

Sprabronze C*	G120 - P-W Carborundum Vitrified
Sprabronze M**	36 - N-E Carborundum Vitrified
Sprabronze T**	36 - N-E Carborundum Vitrified
Copper**	36 - N-E Carborundum Vitrified
Monel	G60 - P-W Carborundum Vitrified
Nickel	G60 - P-W Carborundum Vitrified
Metcoloy No. 1	401 - P-30 Aloxite Vitrified
Metcoloy No. 2	36 - N-E Carborundum Vitrified
Sprasteel 10	36 - N-E Carborundum Vitrified
Sprasteel 25	36 - N-E Carborundum Vitrified
Sprasteel 40	36 - N-E Carborundum Vitrified
Sprasteel 80	36 - N-E Carborundum Vitrified
Sprasteel 120	36 - N-E Carborundum Vitrified

Notes:

Wheel Speed	Approximately 6100 S.F.M. Peripheral Speed
Work Speed	Approximately 80 S.F.M. Peripheral Speed
Traverse Speed, Roughing	Approximately 3 feet per minute
Finishing	Approximately 2/3-foot per minute
Infeed	Roughing - (See ***)
Finishing	No infeed (dwelled cut)
Coolant	Soluble Oil - 50 to 1 percentage

** Slow traverse (approximately 1/2-foot per minute) and high work speed (approximately 140 S.F.M. peripheral speed) are absolutely essential in grinding Sprabronze C. High traverse rates cause the wheel to load badly and give a poor finish.*

*** Wheel G60-P.W. is also recommended for Sprabronze M, Sprabronze T and Copper. It will give almost the same grinding action with an improved type finish.*

**** Maximum infeeds and production rates were not determined due to the many types and sizes of work and equipment which will be encountered in the field. It is suggested that final traverse speeds and infeeds be determined under the prevailing local conditions and requirements.*

Figure 6–20.—Wet grinding recommendations.

The SHAPER OR PLANER should be used to finish flat surfaces that have been metal-sprayed. The only precautions necessary are: (1) remove by filing or grinding any raised sections or overlapping "flash," and (2) take light cuts.

POLISHING sprayed metal requires no special skill on the part of the operator other than the understanding and

realization that he is polishing not a solid piece of metal but a thin veneer which is bonded to the base metal mechanically, rather than by fusion. The main troubles in polishing sprayed metal are (1) cutting through the coating with the edge or corner of the disk or wheel, (2) roughing off too much stock, (3) blistering due to local heat caused by a "loaded" wheel, and (4) blistering due to heat generated during buffing.

QUIZ

1. In what way do case-hardening processes differ from other heat-treating processes?
2. Which type of heat treatment is used to obtain a hard wear-resistant surface on a tough, ductile core?
3. Name four heat-treating operations which involve no change in the chemical composition of the metal.
4. What are the principal reasons for adding alloying elements to steel?
5. What property does carbon contribute to all steels?
6. Name three methods of case-hardening.
7. What effect does the addition of chromium have upon the hardness of a steel?
8. What type of steel contains cobalt?
9. From figure 6–3, determine the critical working point of a 1-percent chromium steel with 0.30 percent carbon content.
10. What determines the depth to which an article is case-hardened?
11. What is the greatest depth of case obtainable in a case-hardening process?
12. What advantage does cyaniding have over other case-hardening processes?
13. Which of the case-hardening methods can be used only with a special steel which contains aluminum?
14. What are the two basic design errors which might cause a tool to crack during heat-treatment?

15. Why is it necessary to avoid overheating when bronze-surfacing a steel part?

16. What three general types of materials are used for hard-facing? In what form are they furnished?

17. Why is it NOT advisable to attempt to hard-face a high-speed steel?

18. What quenching method should be used after heat treating a piece of steel which has been hard-faced?

19. How must hard-facing deposits be finished to the proper size and shape?

20. What method is ordinarily used for applying hard-surfacing material to small parts?

21. What are the three steps in the metalizing process?

22. What metals or alloys can be used as materials for metalizing?

23. Describe the spray gun which is used in the metalizing process.

24. What error is frequently made by operators in metalizing flat surfaces with fast-spraying metal?

25. Should sprayed metal be finished by wet grinding or dry grinding?

26. What grain and bond are necessary in a wheel used for grinding sprayed metal?

CHAPTER 7

MAIN STEAM PROPULSION PLANTS

BASIC STEAM PLANT

The primary function of a marine engineering plant is to convert the chemical energy of fuel oil into useful work, and to employ that work in the propulsion of the ship and the operation of auxiliary machinery. The fundamental principle of the steam propulsion plant is the steam cycle. Figure 7–1 shows a sketch of a basic steam cycle.

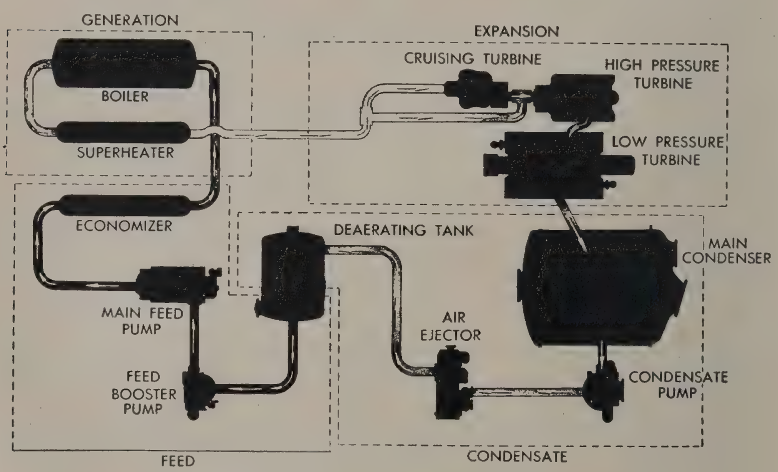


Figure 7–1.—Basic steam cycle.

Water is heated and converted into steam in the generating tubes of the boiler. The saturated steam then passes into the superheater tubes of the boiler where additional heat is applied to raise its temperature and transform it into superheated steam. This superheated steam leaves the boiler, through the main steam line, passes into the high pressure turbine and then to the low pressure turbine. The turbines convert the thermal energy of steam to mechanical energy or work. When no more work can be obtained from the steam because of its low temperature and pressure, it is exhausted into the main condenser. Sea water flowing through the numerous tubes in the condenser cools the exhaust steam and condenses it into water.

Air ejectors help to maintain a vacuum in the condenser. This vacuum allows the steam from the turbine to be exhausted into the condenser against a lower back pressure; thus extra work is obtained from the steam before it leaves the turbine.

The condensate (water) is pumped from the bottom of the condenser and passes through the air ejector condenser on its way to the deaerating tank. The purpose of the deaerating tank is to heat the condensate by exhaust steam and remove oxygen (deaerate) by mechanical means. The tank also acts as a reservoir in which to store water to take care of rapid fluctuations in the system, and it serves to maintain positive suction pressure on the feed booster pumps. The condensate now becomes feed water and flows down to the feed booster pump, where it is pumped to a main feed pump.

The main feed pump discharges the feed water, under a high pressure, to the boiler control feed valves. This pressure must be higher than the pressure of the boiler. The feed water passes through the economizer of the boiler, where it is heated by flue gases, before it enters the stream drum to complete the steam cycle. Additional water as required is added to the system from a make-up feed tank, to replace losses of water from the system. This water is drawn into the main condenser by opening the valve in the line from the feed tank.

The preceding description covers only the bare essentials of a steam plant. Naval ships may have 1, 2, or 4 main enginerooms and from 2 to 12 boilers located in from 1 to 6 firerooms. Most ships have 2 boilers in each fireroom. Most of the pumps and much of the auxiliary equipment are furnished in duplicate units to provide for continuous operation of the main plant in case of derangement of one of the vital pumps or units of equipment. The number of lines and valves in each piping system is increased to allow for flexibility of connecting or isolating main and auxiliary machinery units to or from the system. The purpose, as before, is to provide for the maximum continuous operation of the main propulsion plant in case of engineering casualties and battle damage. With this in mind, most naval ships are built with two or four entirely separate engineering plants.

The engineering plant on a naval warship can be operated in different arrangements or conditions; part or all of the boilers and machinery can be placed in operation as needed to meet speed and safety requirements. During battle conditions all boilers and machinery are placed in operation and the piping systems split to provide individual engineering plants, thus affording maximum protection against the effects of battle damage and engineering casualties. This is known as a split-plant set-up. During peacetime cruising at low speeds in safe waters only part of the ship's boilers are used, and the minimum required machinery is operated or made ready as standby units. The cruising turbines are used to further increase the economical operating conditions of the engineering plant. Destroyers use one of the two firerooms during peacetime operations except during full-power runs or short periods of high-speed maneuvers. When the piping systems are connected for operating one fireroom with two enginerooms, the plant is said to be "cross-connected."

BOILERS

The purpose of any boiler is to convert water, by means of heat, into steam at the temperature and pressure necessary

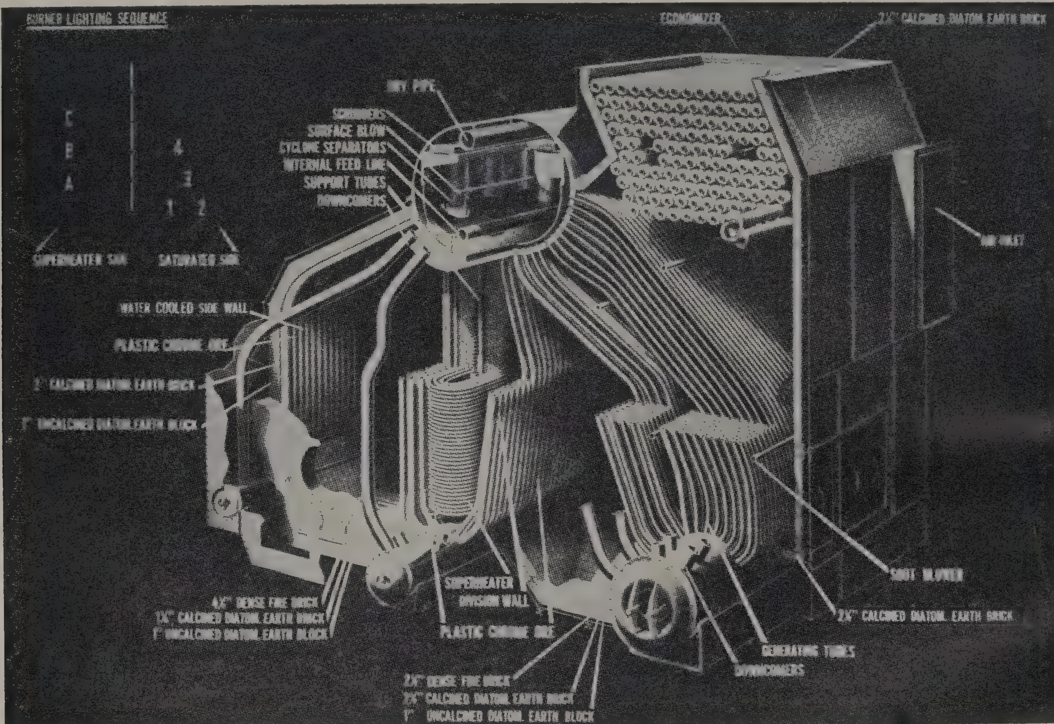


Figure 7–2.—Two-furnace single-uptake superheat control boiler.

for use as the driving force for machinery. On modern naval steam-driven ships the boilers are of the fuel oil burning water-tube type.

Figure 7–2 shows the construction and the names of the parts of a boiler that has been adapted for general naval use. The size of the boiler varies with the type of ship.

This type of boiler generates superheated steam with a controlled, integral, convection or radiant type superheater and an economizer. It has a single uptake and a divided furnace.

Because of the special conditions under which naval boilers must operate, definite minimum requirements are specified for a boiler for naval use. These requirements are:

1. Minimum over-all size and weight.
2. Maximum flexibility; i. e., ability to maintain steam pressure constant under wide and rapid fluctuations of steam load, as during maneuvering of the ship, and ability to raise steam rapidly from cold conditions.
3. Reliability; i. e., ability to maintain the steam output at the designed temperature over a wide range of steam generating rates, to permit safe and efficient operation unaffected by gunfire and ship's motion and with a high factor of safety.
4. Maximum efficiency over a wide range of steam generating rates.
5. Maximum accessibility for inspection, cleaning, and repair.

Lighting Off Boilers

A slightly different procedure for lighting off must be followed on each ship. The procedure will vary according to the type of ship, and the equipment installed. The particular circumstances under which the boiler is being put into operation may also vary the procedure. A check-off list is used to itemize the starting procedure for each boiler installation. The Navy Training Course, *Fireman*, NavPers 10520, gives details for lighting off a boiler; this material

should be reviewed at this time as the details will not be covered in this book.

When lighting off a boiler, it must be remembered that permission must be obtained from the officer of the deck, who in turn obtains the necessary permission from the captain (if aboard), or the senior duty officer. This request is transacted by the control engineroom or the engineer officer.

The main control engineroom, under the supervision of the engineer officer, controls all operations of the engineering plant, including lighting off, operating, and securing boilers.

It is good engineering practice to allow ample time for lighting off boilers. Usually 2 hours are allowed for lighting off and cutting in a boiler on the line. More time may be required in extremely cold weather or if there is new brickwork in the furnace. In case of an urgent or emergency condition a boiler can be lighted off in a very short time. Under normal conditions time is allowed for carrying out the required inspections, tests, and safety precautions. Machinery, also, must be properly warmed up; the stack cover (if on) must be removed; and time should be allowed to take care of minor unforeseen repairs that may have to be made.

One of your first jobs when lighting off a boiler will be to line up the various piping systems and check to see if the proper valves are closed or opened as required by the lighting-off procedure.

Boiler feed water tanks are lined up for regular, standby, and emergency suction—the amount and quality of feed water on board must be known at all times.

The fuel oil service tanks are lined up for regular and standby suctions, after being sounded and checked to see if any water is present. Water is removed by stripping via the low suction. This is usually done by the oil king.

As in the case of other boilers with superheaters, the boiler illustrated in figure 7–2 requires additional precautions in regard to the superheater. These are:

1. The superheater must be thoroughly drained during the lighting-off period.

2. At no time while raising steam in a boiler should fires be lighted under the superheater side unless an adequate steam flow has been established through the superheater.
3. At no time should a burner be lighted on the superheater side unless one or more burners are in operation on the saturated side.

When the steam pressure comes up to within 100 psi of operating pressure, it is customary to test the safety valves by hand. Permission to do this must be obtained from the officer of the deck.

Before cutting in the boiler on the auxiliary and main steam lines, precautions should be taken to drain the lines properly. Steam lines should be warmed up to prevent water hammer, carry-over, and leaky piping joints. The boiler is cut in first on the auxiliary steam line, then on the main steam line. Superheaters are not used in the "in-port" procedure of cutting in boilers on the main steam line. When the ship is under way, the superheat temperature of all boilers is dropped below 600° F., at the rate of about 50° F. every 5 minutes, before the incoming boilers are cut on the line.

Control of Boilers

The number of men on watch to cover the necessary jobs will vary with the type of ship. In general, the set-up is as follows: one PO in charge, one checkman per boiler, one blowerman per boiler, one burnerman for the saturated side and one for the superheated side per boiler, one or two men for the auxiliary machinery, one man for the JV phones, and one messenger—working together as a team.

To operate boilers properly, the petty officer in charge of the watch must know what is demanded in regard to ship's speeds and steaming conditions. He should have full information of the conditions in the boilers he is controlling. Generally, the steam pressure is kept at a standard value and superheat temperature is set by the control engineroom.

The control of air pressure, fuel pressure, number of burners, and other items are controlled by the petty officer in charge of the fireroom.

While a boiler is being operated under steady steaming conditions with the superheater side in use, the superheater outlet steam gage and thermometer should be kept under constant observation. Any minor load change should be taken care of by manual readjustment of the fuel oil pressure-regulating valve for the two sides of the boiler, in order to maintain the desired steam pressure and temperature.

Under maneuvering conditions and with the superheater in use, it is particularly important to keep a constant check on the main steam temperature and pressure. When the superheater is in use, a steam flow must pass through it at all times. To meet the changes in load called for by speed changes, it will be necessary to cut out or cut in burners under both the saturated and superheater sides. On a reduction in load, first cut out one burner on the superheater side, then one on the saturated side, and if necessary, continue this procedure until all burners have been extinguished. On an increase in load, first cut in two burners on the saturated side, then one on the superheater side until the load requirement has been met.

When practical, the soot blowers should be used once during each watch underway and twice each day while at anchor. The minimum requirement for blowing tubes is twice each day under way and once each day while at anchor.

Securing Boilers

When securing superheat control boilers, the procedure is the reverse of cutting them in on the line. With more than one boiler on the same line, drop the superheat off the boilers to 600° F. at the rate of about 50° F. every 5 minutes, shift the load to the steaming boiler(s) and secure superheater fires; then secure the saturated fires on the boiler(s), and close the outgoing boiler stops. After the boiler pressure has dropped to that prevailing on the high-pressure

drain system, the superheater header drains should be opened to the bilges. It is good practice to blow tubes on the boiler(s) being secured. (Port regulations regarding the pumping overboard of fuel oil or oily water from the bilges must be strictly observed.)

Boiler Safety Precautions

Listed here are a few safety precautions to be observed while lighting off, during operation, and after securing the boiler.

Prior to placing the boiler in service:

1. Adhere strictly to the prescribed tests of safety valves.
2. Test all automatic features and safety devices for proper operation.
3. In lighting off, run water out of sight in water glass and then, with emergency or auxiliary feed pump, bring the level to about 1 inch above the bottom of the 10-in. gage glass.
4. Blow through the furnaces with air before lighting off and before relighting when all burners have been secured, accidentally or otherwise, except on the superheated side of superheat-control boilers.
5. Make it a standard practice to use a torch in lighting off additional burners; never light a burner from hot brickwork.
6. Be sure that the protective steam is lined up before lighting off the first burner in boilers with integral superheaters (no control).
7. Never cut in burners at a greater rate than prescribed to meet the ratio of pounds of fuel per hour to the square foot of water screen surface.
8. Never light off a burner on the superheater side of a superheat-control boiler until the steam flow is established through the superheater.
9. Alternate registers while lighting off, to ensure even heating of the brick and tubes.

During operation of the boiler:

1. Do not exceed the authorized maximum steam pressure and temperature.
2. Never relight atomizers from a hot brick wall.
3. Test the fuel oil heater drains at least once each hour.
4. Do not use oil from a tank containing water.
5. Make the required tests for water in fuel oil service and storage tanks.
6. In case of water in the fuel oil, clear the fuel oil service piping by means of the burner clearing line. If this fails, notify the engineroom and secure the boiler.
7. Never completely shut off the feed supply to a boiler as long as the boiler is furnishing steam.
8. The Boilerman assigned to the checks should have no other duty than that of maintaining the proper water level in the boiler.
9. Blow through the water glasses once each hour.
10. Never leave disconnected atomizers in place.
11. Never empty a boiler with a bottom blow, except in an emergency.
12. Cut out the boiler at once, if practicable, whenever a brick drops out of the furnace lining.

After securing the boiler:

1. Remove the atomizers from the registers as soon as possible after securing.
2. Close up the furnace tightly as soon as all the atomizers have been extinguished.
3. Pump the water level to three-fourths of a glass on cutting out a boiler after it ceases to require more feed.
4. Never remove any pressure part of a boiler before taking definite steps to ensure that there is no pressure within the boiler.

The above safety precautions are by no means complete. When more detailed information is required, chapter 51 of BuShips *Manual* should be consulted.

Low Water in Boiler

Low water is one of the most frequent and most serious causes of trouble in the fireroom. In nearly all cases it re-

sults from inattention on the part of the Boilerman in charge and the man tending the checks, or because their attention was diverted to some duty other than the major one—that of maintaining the proper water level in the boiler. An unaccountable drop in steam pressure when steaming a boiler is a possible indication of low water.

Except for momentary fluctuations during rapid maneuvering, whenever the water in the boiler falls from sight in the water gages the procedure is as follows:

1. Shut off the oil supply to all burners.
2. Close the feed-check valves.
3. Close the boiler steam stop valves.
4. Open the safety valves by hand cautiously and relieve the boiler pressure gradually.
5. Close the burner register shutters and stop the forced draft blowers.

High Water in Boiler

The first three steps for a high water boiler casualty are the same as those for low water; therefore, there is no need for any delay in trying to determine whether it is a high or low water casualty.

The procedure for a high water casualty is as follows:

1. Shut off the oil supply to burners.
2. Close the feed-check valves.
3. Close the boiler steam stop valves.
4. Blow through the water gages to determine definitely whether the gages are full or empty.
5. Blow the boiler down until the water level is approximately at the designed level.
6. Relight the burners and cut the boiler in the line in the usual manner.

Loss of Fuel Oil Suction

When the oil in the tank feeding the service pump falls to the level of the suction line, a mixture of oil and air is pumped to the atomizers. The atomizers at once start to

sputter excessively. When the sputtering is detected, shift the service pump suction to another tank at once, being extremely careful of flare-back.

Should the suction of the service pump become lost, the fire will go out. The fireroom force should close the boiler stops at once in order to hold as high a steam pressure as possible in the boilers. This having been done, the valves in the steam lines should be adjusted so that when the boiler stops are again opened, all the steam available is directed only to the oil service pumps. It is advisable to use atmospheric exhaust so as to make unnecessary the use of steam to run condensing apparatus. Regain the suction of the fuel oil service pump and light off one atomizer. This is assured if at least 75 psi pressure is held on the boiler after closing the stops. The same procedure is carried out when a considerable amount of water is in the oil, except that the oil in the manifold and piping should be pumped overboard or into a contaminated oil tank.

Boiler Tube or Pressure Part Carries Away

To prevent serious injury to personnel and to reduce to a minimum the extent of damage to the boiler, whenever a large steam leak occurs in a boiler the following action should be taken, as far as the particular circumstances permit:

1. Close boiler steam stop of the damaged boiler.
2. Simultaneously with step 1, or as soon as possible thereafter, open the safety valves gradually, to relieve the pressure.
3. Shut off the supply of oil to the burners.
4. Close the burner register shutters.
5. If the blowers are running, increase their speed, if necessary, to drive the escaping steam up the smoke pipe and keep it out of the fireroom.
6. Except in cases of tube failure due to low water, when consequent overheating is involved, continue its feed supply until fires are out, to prevent the heating surfaces becoming uncovered and burned. In such case start

the auxiliary feed pump after the auxiliary feed check has been opened. The main feed supply shall be shut off, if other boilers are being fed from the latter. Special care must be taken to maintain the water at the proper height in all other boilers in use and to provide additional water from the reserve tanks, if necessary, to prevent a shortage in the main feed tanks.

7. After the pressure has decreased and the fires are out, stop the blowers and close all possible sources of air flow into the boiler furnace. Allow the boiler to cool off slowly.

MAIN TURBINES

The turbine installations in the Navy vary to such an extent that detailed instructions cannot be given in this book. The manufacturer of each type of turbine issues detailed instruction books and drawings for the individual installations. The common type of turbine installation consists of three units—the high-pressure, low-pressure, and cruising turbines. The astern turbine is designed and built as part of the low-pressure turbine. Figure 7–3 shows a typical naval installation of main turbines and the reduction gears for one engineroom. The size and details will vary for different types of ships but nearly all ships follow the general pattern. The cruising turbine with its reduction gear is added to the plant for reasons of economy. A naval warship operates most of the time at speeds far below full power, thus requiring, at cruising speeds, only a fraction of the power for which the main turbines are designed. Besides being used for high speeds, the full power (high-pressure) combination is used when getting under way, when coming to anchor, and when steaming in narrow channels and dangerous waters.

Warming Up Main Turbines

Engineroom preparations for getting under way consist of starting the necessary auxiliaries and warming up the

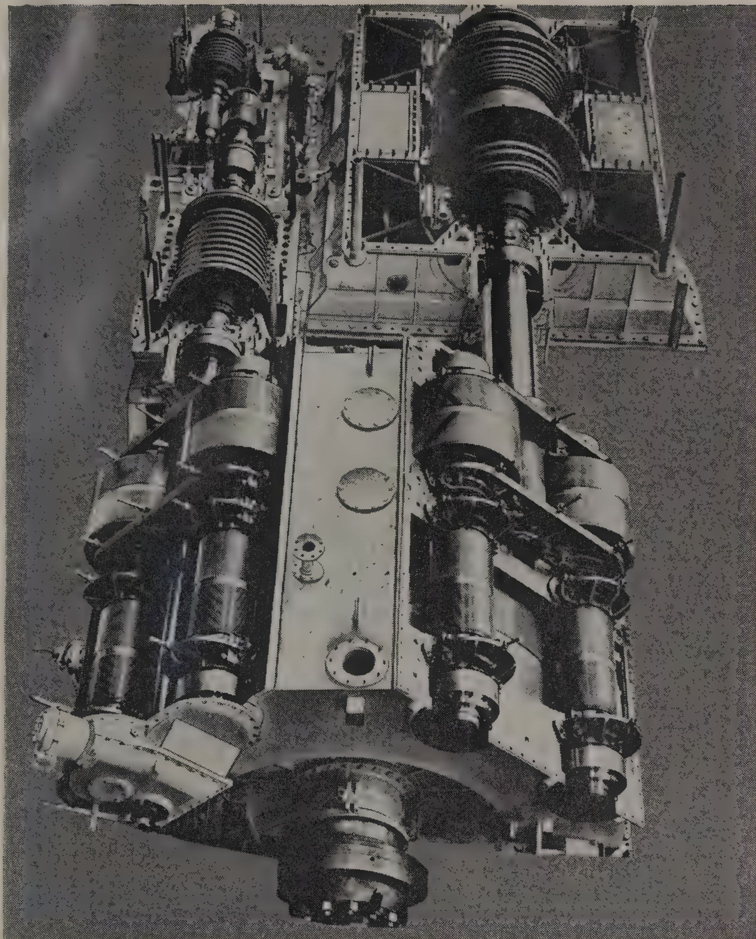


Figure 7–3.—Steam turbine and reduction gear with casings removed.

main turbines. During this warming-up process the temperature of the various parts of the installation is raised from the temperature of the surrounding atmosphere to approximately that of operation. While this change in temperature is taking place, the metals in the various parts of the installation expand; in order to prevent inefficient operation and damage due to distortion, the procedure must be such that all parts of the main turbines are evenly heated.

The lubrication oil system must be placed in operation before the turbine rotors are turned over. The main steam line, strainer, throttle, and turbine drains must be opened to insure that all water will be drained from these parts. The main steam line must be warmed up slowly to prevent leaks at the joints.

During warming-up operations turbine rotors shall not be permitted to remain at rest for any appreciable time while steam, including gland steam, is being admitted to the turbine.

The turning (jacking) gear is engaged and the turbine rotor is turned over before steam is admitted to the turbine glands. The turning gear may be disconnected and the turbine spun after sealing steam has been admitted to the glands for not less than 15 minutes. Turbines not provided with turning gear should be spun as soon as gland steam is admitted to the turbine. It is important that the first opening of the throttle valve be sufficient to start the turbine rolling at once to avoid unequal heating of the rotor and consequent distortion.

The main condenser and the air ejectors should be placed in operation prior to admitting steam to the gland-sealing system. Only the second stage of the air ejectors is used, which should produce a vacuum of approximately 25 in. Hg on the main condenser. The first stage should be cut in just prior to reporting the engineering department ready for getting under way.

Auxiliary exhaust steam should not be admitted to the main turbines during the warming-up period.

In preparation for being ready for getting under way, the turning gear is disconnected and process of spinning the rotors is used. Permission to spin the rotors must first be obtained from the OOD. The throttle valve is opened enough to admit a puff of steam sufficient to start the rotors turning. Care should be taken not to put way on the ship. It is preferable to open the astern valve first, as any condensate inadvertently left in the piping will be discharged more

readily, without damage, through the large nozzles and fewer rows of blading of the astern turbine, than through the ahead element. After the turbines have been spun astern, repeat the process immediately with the ahead throttle. For high-speed turbines driving double reduction gears, this procedure should be repeated every 3 to 5 minutes.

Securing Main Turbines

When the ship has completed anchoring or mooring, and after proper orders have been received, the main turbines are secured. The throttle valves and main steam stops are closed, and the turbine and throttle drains are opened. Immediately after the throttle valves are closed, the turbine rotors should be turned over continuously by the turning gear while cooling off. During this jacking period of at least 2 hours, the lubricating oil pressure should be maintained on all bearings. The main steam line must be drained thoroughly before the drains are secured. Then the turbine is thoroughly cooled and within 24 hours the turbine drains are closed.

Safety Precautions for Turbines

The following safety precautions in regard to main turbines must be observed:

1. Do not use auxiliary exhaust steam for warming up the main turbines.
2. Be sure that the lubrication system is in operation before turning over the main engines.
3. Keep the rotors turning continuously while warming up the main engines.
4. Never fail to investigate any noise emanating from a turbine.
5. Do not put way on the ship when turning over the main engines.
6. If a turbine vibrates, slow down, investigate, and endeavor to locate the cause.

7. Except in an emergency do not admit steam into the astern turbine until steam has been shut off from the ahead turbine, or vice versa.
8. In getting under way be sure that all lines are properly drained in order to prevent danger from water hammer.
9. When steam pressure drops, do not open the throttle to such an extent that the working pressure of the steam is brought to a dangerously low point.
10. Stop the engines if the oil supply fails.
11. If the throttle valve sticks open, close the guarding valve or bulkhead stop as soon as possible.
12. Extreme care must be taken to prevent the entry of foreign matter into the turbine when it is opened for inspection.
13. About 24 hours after securing and when the turbine is thoroughly cooled, close the turbine drains.
14. Do not exceed the astern power rating for the turbine.
15. Where applicable, do not exceed the maximum speed limit when operating with one shaft in a locked position.
16. Maintain the proper radial and axial position of the turbine rotor.

Main Turbine Casualties

The importance of continuous operation of the ship's engineering plant is evident when the ship is in restricted waters and during battle conditions. When casualties occur to any part of the main installation, or to vital auxiliaries, the standby machinery must be started before searching for the cause of the trouble. The officer of the deck should be notified as soon as practical if the casualty is such that the engine will either have to be slowed down or stopped.

Vibration of and Unusual Noise in Turbines

If at any time while the turbine is in operation it suddenly begins to vibrate abnormally, the trouble may gen-

erally be traced to any one or a combination of the following troubles:

1. Water being carried over from the boilers.
2. Bearing troubles.
3. Bent or broken propeller blades.
4. Broken or missing turbine blades or rubbing of blades.
5. Rubbing of carbon packing, labyrinth packing, or oil seal rings.

If the trouble is due to water being carried over, the trouble may be overcome either by proper operation of the boilers or by slowing down the main engines.

If a rumbling sound is heard from the turbine when it begins to vibrate, the trouble is undoubtedly due to water or other foreign matter in the turbine. If, after slowing down or correcting faulty boiler operation, the trouble is not eliminated, the turbine must be shut down, except in case of emergency, and the interior of the turbine must be inspected at the earliest opportunity. If a sharp metallic sound is heard after the rumbling noise, it may be assumed that part of the blading has been damaged and the turbine must be shut down and not used until the cause of the trouble has been ascertained and repairs made.

If vibration is caused by rubbing of carbon packing, labyrinth packing, or oil seal rings, the shaft will overheat due to friction and will start to show heating colors; in such cases refit the affected parts to proper clearances.

Loss of Lubricating Oil Pressure

Extensive derangements of main propulsion machinery have resulted from the loss of lubricating oil pressure. In many instances the loss of lubricating oil pressure has been due to improper operational procedure rather than material failure; and the resulting damage has been unnecessarily extended by the following unsound procedures after failure of lubricating oil supply:

1. Partial checking of shaft speed, instead of stopping shaft rotation.

2. External examination of bearings, including check of sight flows and temperatures, which usually appear normal, rather than thorough examination.
3. Resumption of operation, with aggravation of the damage.

Upon failure of the standby pump to cut in, or other indications of loss of oil pressure, the throttleman will immediately take action to stop the affected shaft, and simultaneously notify the bridge of the casualty and the action being taken. The engineroom personnel will at once take steps to regain lubricating oil pressure.

If steam pressure is available, close the ahead throttle and stop the shaft by use of the astern throttle. (If the astern engine is in operation, close the astern throttle and open, or keep open, the ahead throttle.) Engage the jacking gear and apply the jacking gear brake. If speed is in excess of one-half of full power speed, it may be necessary to slow down the ship in order to stop the shaft and engage the jacking gear. The ship's speed may then be increased to the limit for locked-shaft operation.

If steam pressure is lost in one engineroom during split-plant operation and unless the tactical situation positively prevents, take way off the ship by backing the other engine(s). Concurrently determine the nature of the casualty or damage causing the loss of steam. If it will not cause loss of steam to the other plant, open auxiliary and main steam cross-connections immediately. If damage would cause loss of steam to the other plant, isolate damage and then open auxiliary and main steam cross-connections as soon as practicable. Stop and lock the affected shaft as soon as steam is available.

Concurrently with above conditions, make every effort to regain lubricating oil pressure without interfering with or delaying the primary action of stopping and locking the main shaft. Proceed as follows:

1. Check the lubricating oil pump in use. If it is not operating, start the standby pump.

2. Shift the duplex strainers.
3. Check the sump level. If low, replenish oil.
4. Locate and repair any leaks.

When the shaft has been stopped and locked, carry out the following procedure:

1. Inspect all bearings and endeavor to determine which have been overheated. Do not rely on thermometers alone. A thermometer may have indicated only a slight, unobserved, momentary rise.
2. Secure gland sealing steam and the main air ejectors to minimize main turbine rotor distortion.
3. Inspect and clean lubricating oil strainer basket not in use. Note whether flakes of bearing metal are present in strainer.
4. Start lubricating oil purifier if not in use.
5. Continue circulation of lubricating oil until bearings are sufficiently cool for inspection, and maintain the lubricating oil system in operation at all times except when inspecting bearings so that lubrication will be provided if shaft-locking gear should fail.
6. Take bearing-wear micrometer readings of all bearings and axial clearances where means are provided.
7. Proceed with the inspection of bearings. Raise bearing caps and roll out shells. The inspection must be as thorough as circumstances will permit; the importance of subsequent reliable performance must be weighed against the time required to inspect suspected bearings.
8. It is possible that the bearing trouble is isolated and only one or a few bearings are wiped. It is realized that a thorough examination of the main reduction gear bearings may not be practicable immediately following such a machinery derangement, but the following procedure is recommended:

a. All turbine and cruising reduction gear bearings should be thoroughly inspected.

b. Main reduction gear bearings that are accessible without lifting the gear casing should be thoroughly inspected.

Inaccessible main reduction gear bearings should be examined through inspection openings for flow or babbitt along the shaft.

c. Reduction gear bearing thermometers should be removed to check for oil flow from the wells. Absence of oil flow from a well indicates that the oil passage to the thermometer has been closed by wiped bearing metal.

d. The oil strainer basket in use should be examined for the presence of babbitt flakes.

e. If examination of main reduction gear bearings shows no indications of wiping and only one of the turbine and cruising reduction gear bearings is found to be wiped, the main reduction gear bearings may be assumed to be undamaged, and the shaft may be operated at the minimum speed which the tactical situation will permit until a thorough examination can be made.

f. If several of the turbine and cruising reduction gear bearings are found to be wiped, it is probable that some of the main reduction gear bearings are also wiped, and the shaft should not be operated until proper inspections and repairs are made.

g. The above procedure (f) applies when lubricating oil pressure on the whole system is lost. However, if it is noted that a bearing is overheating because of local loss of oil or presence of foreign matter and it is necessary to shut down the turbine, it should be slowed down but kept turning over at a slow speed until the bearing and journal have cooled sufficiently. If the shaft motion is stopped quickly, the bearing metal may freeze to the shaft and make repairs much more difficult.

REDUCTION GEARS

General

Turbines must operate at high speeds in order to utilize the steam most efficiently. In the case of the ship's propellers, however, the range of best efficiency occurs at relatively low speeds. To provide for the high speed of the turbine

and the low speed of the propeller, mechanical reduction gears are employed.

Most gearing in use at the present time is of the double helical type, a right-hand and left-hand helix being used to balance the fore and aft components of the tooth pressure. The helical gear produces a smooth action and eliminates tooth shock. The involute tooth contour is universally used because the action of the teeth is unimpaired if the distance between the center lines of the gear and pinion shafts is slightly increased due to wear of bearings. Single- and double-reduction gears are used.

Pinions are made of forged steel, and the teeth are usually cut directly on the outside surface of the pinion shaft.

The gear wheel construction and material depend upon the size. For small gears the entire gear wheel may be made from a single steel forging; all large gears, however, are built up in sections. These sections usually are the shaft, the center or body, and the rim in which teeth are cut. The shaft is always of forged steel with the main shaft coupling flange integral at the after end, and usually with a removable collar for thrust bearing at the forward end.

Gear casings generally are weldments of steel plates and simple castings. Gear case covers are bolted to the upper casing and arranged so that their removal makes the bearing caps accessible for routine inspection of the bearings. Suitable inspection plates are provided in covers and gear cases, so that rotating parts may be sighted.

Operation

The efficient lubrication of reduction gears is of the utmost importance. Oil at the designated working pressure must be supplied to the gears at all times while they are being turned over, either with or without load. The lubricating system must be kept clean. Particles of lint or dirt, if allowed to remain in the system, are likely to clog the oil-spray nozzles.

The oil must be free from all impurities such as water, grit, and any particles of metal. Water is especially dangerous;

even small amounts soon cause pitting and corrosion of the gear teeth. Acid is equally dangerous. The oil must be tested frequently for water and acid content.

The oil level in the bottom of the gear case must not be allowed to rise above the lower level of the gears; otherwise the gears will churn and emulsify the oil, causing a sudden increase in its temperature. If this occurs the engines must be slowed or stopped until the excess oil can be removed and normal conditions restored. An inspection should be made for any presence of salt water in the oil. Routine checks should be made to see that the lubricating oil is kept at the proper level. Any sudden loss or gain in the amount of oil should be immediately investigated and accounted for.

Spray nozzles to gears must be kept open at all times. No oil-spray apparatus, fitted for the lubrication of gears or pinions, can be removed, altered, or rendered inoperative without the authority of BuShips.

Before getting under way, and frequently during each watch, the supply of oil to the gears and bearings must be inspected.

If the supply of lubricating oil to the gears should for any reason fail, the engines must be stopped. The gears must not be placed back into operation until normal conditions have been restored and an adequate inspection has been made for possible damage to the gears and bearings.

If it is known that bearings have been overheated, the gears must not be operated, except in cases of extreme emergency, until after the bearings have been disassembled and examined and any defects remedied. Failure to observe this precaution may result in serious damage.

A properly operating gear has a certain definite sound, which the trained operator can easily recognize. The cause of any unusual noises should be investigated.

Under certain changing conditions of speed there is a point where the thrust shifts from the bottom half to the top half of the reduction gear bearings. When this shift in thrust takes place, there is apt to be a slight jarring or

vibration in the gear case, due to jumping of the pinion journals by the amount permitted by the journal clearance. This unstable condition may be brought about when operating at very slow speeds during the time when alternate ahead and astern bells are used, or when going slowly ahead on one screw while going astern on the other. It also may be caused by very shallow water. In ordinary maneuvering the transition from one direction to another takes place so quickly that it is not noticed. The operating personnel should be familiar with this unstable condition in order to distinguish it from conditions that are not normal—such as vibration caused by faulty alignment of the reduction gear or main shaft, bent main shaft, damaged propellers, etc., or by improper balance.

Safety Precautions

1. An ample quantity of the proper quality of clean lubricating oil should be applied to the gears at all times while they are in operation.
2. In case of churning or emulsification of the oil in the gear case, the gear should be slowed or stopped until the defect is remedied.
3. If for any reason the supply of lubricating oil to the gears fails, the gears should be stopped until the cause can be located and remedied.
4. When bearings are known to have been overheated, gears should not be operated, except in cases of extreme emergency, until bearings have been examined and defects remedied.
5. If excessive flaking of metal from the gear teeth occurs the gears should not be adjusted, except in case of emergency, until the cause has been determined; care should be taken to prevent, as far as possible, the entry of the flakes into the general lubricating system.
6. Unusual noises should be investigated at once, and the gears should be operated with caution until the cause is discovered and remedied.

7. Bearing and thrust clearances should be checked, if possible, before operating at full power.
8. No inspection plate, connection, fitting, or cover which permits access to the gear casing should be removed without specific authority of the engineer officer.
9. The immediate vicinity of an inspection plate joint should be kept free from paint.
10. When gear cases are open, precautions must be taken to prevent the entry of foreign matter. The openings must never be left unattended unless satisfactory temporary closures have been installed. Before an inspection plate or cover is replaced, a careful inspection should be made by a responsible officer to ensure that no foreign matter has been left inside the gear casing.
11. Inspecting personnel must remove from their clothing all loose items (pencils, cigarettes, matches, lighters, flashlights, wrenches, etc.) before attempting to look through any inspection opening.
12. Lifting devices must be inspected carefully before being used, and should never be overloaded.
13. Naked lights must be kept away from vents while gears are in use, as the oil vapor may be explosive.
14. Waste or material leaving lint should not be used in cleaning the lubricating system, bearings, or gears.

MAIN CONDENSER

The function of condensers is to maintain a vacuum and recover feed water. The proper performance of this function is of vital importance to the proper operation of steam-propelled ships.

The construction details of condensers will vary for different installations, but their principle of operation remains the same. Steam exhausted from the low-pressure turbine enters the condenser through the opening(s) at the top of the condenser. Upon coming in contact with the cold con-

denser tubes, the steam condenses and the condensate collects in the space at the bottom of the condenser, below the tubes, which is called the hot well. The tubes are kept cold by the circulation of sea water which carries away the heat given up by the steam in condensing. The condensate is pumped out of the condenser hot well by condensate pumps.

Effect of Air

If air is allowed to collect and occupy space in a condenser it tends: (1) to insulate the tube surfaces from the steam, and (2) to interfere with the flow of heat, and thus to increase the temperature difference existing between the steam and the circulating water with a corresponding decrease in the condenser vacuum obtainable. Further reduction in vacuum is caused when the partial pressure exerted by the air itself is added to the pressure of the steam in the condenser.

Air may enter the condenser in various ways. A small amount may be dissolved in the feed water discharged to the boilers, to be released with the generated steam and to flow into the condenser with the exhaust steam. Air leakage may occur through improperly sealed turbine glands, through imperfect turbine, condenser, and associated piping joints under vacuum, through leaky condensate pump or valve glands, or by allowing the drain collection tank to go dry. When make-up feed and various drains are discnarged to the condenser, any air dissolved in these drains tends to be emitted from the water under condenser vacuum and to collect in the condenser. It may be noted that air in any part of the steam system may be expected eventually to flow to the condenser, as this unit in the system is the one wherein the lowest absolute pressure is maintained.

If a large air leak develops, the condenser vacuum will be immediately and seriously reduced and corrective measures, such as slowing or stopping the main engines, must be taken at once. Although constant vigilance must be maintained to detect and correct air leaks, a small amount of air will con-

tinuously find its way into condensers during normal operation. This small amount of air is removed from the condenser by means of the air ejectors.

Measurement of Vacuum

Almost all ships provide three independent means for checking the vacuum existing within the condenser.

One of the most important and RELIABLE FUNCTIONS of the DIAL-TYPE VACUUM GAGE is to indicate any rapid, unusual change in vacuum which might require immediate corrective measures.

If the ABSOLUTE PRESSURE GAGE is in proper adjustment and there is no air leak nor condensate in the gage line or any part of the instrument, the absolute pressure readings obtained should correspond closely with dial-type vacuum gage readings properly corrected to standard conditions.

EXHAUST TRUNK MEASUREMENT of the temperature of the steam (not superheated) entering a condenser generally provides a good indication of the condenser vacuum. For conversion of temperature to vacuum, use Table 46–I in chapter 46 of BuShips *Manual.*

Condenser Cooling Water

Sea water is circulated through the main condensers by means of the scoop injection in most ships. With the ship under way (usually more than 5 knots), sea water entering the scoop has sufficient force to enable it to pass through the condenser tubes and back to the sea again. With scoop-circulated condensers under most normal operating conditions, the flow of circulating water is automatically controlled to approximately the correct amount, as governed by the speed of the ship. In order to provide circulation of cooling water when the ship is standing by, going astern, or maneuvering at slow speeds, a circulating pump is provided which usually discharges into the inlet water chest independently from the scoop installation. A nonreturn valve, designed to close automatically with the reversal of water

flow when the main circulating pump is started, is installed in the scoop-piping to prevent water discharged by the pump from backing out through the scoop injection instead of flowing through the condenser. All main condenser circulating pumps are provided with an effective bilge suction connection, and regular drills should be conducted to insure that in an emergency these pumps can be put on bilge suction quickly and effectively.

Gate valves are provided adjacent to the scoop, pump suction, and overboard discharge sea chests, for use in the event of derangement of the sea-water circuit and during condenser upkeep and repair operations requiring draining of the sea water from the unit.

In regulating the flow of circulating water through condensers the following instructions should be complied with:

1. Regulation of water flow for main condensers should not be accomplished by throttling of valves in the water supply piping.
2. In the regulation of water flow by throttling of gate valves in the circulating water discharge piping, gate valves should be kept at least one quarter open to prevent possible pounding of the disk against the valve seat.
3. Condenser water chests normally should not be subjected to a pressure in excess of 15 psi gage.
4. A relief valve set at 15 psi is provided on the condenser inlet water chest. This valve should be lifted by hand when securing the condenser.
5. The quantity of circulating water should always be sufficient to insure that all tubes of the condenser are filled with water.

Condensate Level Control

The condensate in the condenser hot well must be kept at a proper level in order to obtain satisfactory operation of the condenser and the condensate pump. A hot-well gage glass is provided for checking the level of the condensate in the condenser. Most condensate pumps are normally operated at a constant speed. No attempt should be made to

carry a fixed level of condensate in the hot well by controlling the speed of the condensate pump.

Sufficient condensate is kept in the condenser hot well by means of the recirculation piping system. Either an automatic or hand control valve is used to return condensate to the hot well. This will prevent the hot well from running dry and causing damage to the condensate pump, and it also provides sufficient condensate flow through the air ejector condenser for proper ejector operation.

A high or full gage glass will indicate insufficient drainage from the condenser due to (1) malfunctioning of the condensate pumps, (2) improper operation of these pumps by assigned personnel, or (3) the excessive recirculation of condensate.

Normal variations will take place in the water level of the gage glass. The experienced operator must take immediate steps to investigate any abnormal conditions that may occur.

Causes of Inadequate Vacuum

Hot or Flooded Condenser.—If at any time loss of vacuum is accompanied by a hot or flooded condenser, the units exhausting into it must be slowed down or stopped until the condensing plant is again put into proper working order.

Air Leakage.—Constant vigilance must be maintained to detect and eliminate air leakage into a condenser, as this is the most likely cause of a rapid decrease in vacuum under steady operating conditions or of an unexpected decrease in vacuum under maneuvering conditions. Conditions may be such that the operation will be satisfactory for cruising speeds but will prove inadequate for full-power requirements.

Improper Air Removal.—Improper functioning of air removal equipment has an effect on condenser performance similar to that of excessive air leakage. Most air-ejector assemblies serving condensers are fitted with 2 two-stage ejectors, either one of which has sufficient capacity for proper removal of normal air leakage into the vacuum system, with the other two-stage ejector serving as standby.

Improper Condensate Drainage.—Insufficient drainage of condensate from a condenser is the result of malfunctioning or improper operation of the condensate pumps. Care should be taken that excess condensate does not flood the condenser. Besides causing a loss of vacuum, an overflow of condensate in the condenser may reach the turbine and cause major damage.

Insufficient Flow of Circulating Water.—If sufficient circulating water flow is not available, it will become impossible to maintain the required vacuum. The condenser will become hot and pressure will start to build up.

Common causes of inadequate flow of circulating water are:

1. Maloperation or failure of the main circulating pump.
2. Injection and overload discharge sea chest strainers obstructed with foreign matter.
3. Injection and overboard discharge valves not being sufficiently opened, or a valve disk becoming detached from its stem.
4. Foreign matter clogging or shutting off condenser tubes from the circulating water.
5. Improper operation of the air vents to the condenser headers. (In aggravated cases, sufficient air will collect to cause reduction in vacuum due to restricted circulating water flow.)
6. Failure to start the main circulating pump when insufficient supply of water is obtained from the scoop injection, due to slow speeds.
7. Nonreturn valves in the scoop-injection or main circulating pump discharge piping failing to open fully, or to close with reversal of flow.
8. Operation of the ship in shallow muddy waters.

Sea Water Leakage

One of the most frequent machinery derangements aboard steam-propelled ships is the failure of one of the thousands of condenser tubes installed in the condensers, resulting in

the leakage of sea water into the condensate. Continued contamination of the condensate soon results in the impairment or disablement of the entire machinery plant. The condensate from each main condenser should be tested every 15 minutes under way and every 30 minutes while standing by. Most ships are provided with salinity indicator systems. A salt water leak must be detected as soon as possible, so that adequate tests and repairs can be made. High salinity may be caused by a contaminated make-up feed tank; this can be quickly detected by closing the make-up feed valve, or by shifting tanks.

AIR EJECTORS

The function of air ejectors is to remove the noncondensable gases, mainly air, which leak or are discharged into condensers operating under vacuum, and to compress this air to the pressure necessary for discharge from the condensing system. Figure 7–4 shows a schematic diagram of a two-stage air-ejector system.

There are 2 sets of air-ejector elements or nozzles attached to the air-ejector assembly. Each set consists of 2 air-ejector

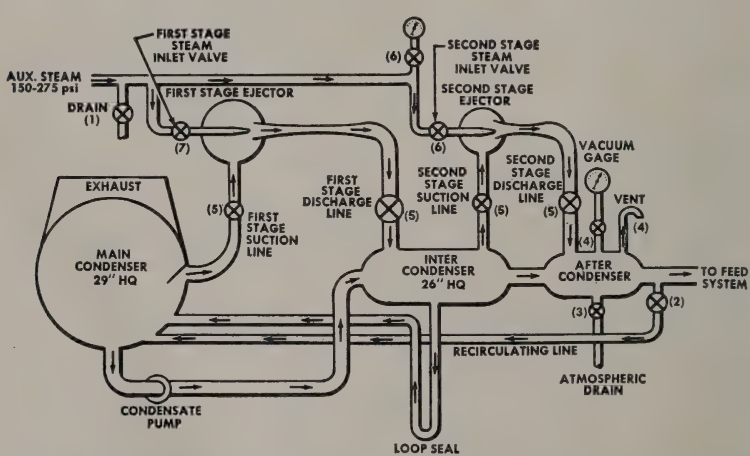


Figure 7–4.—Flow diagram of two-stage air ejector with sequence of operations in starting up.

elements called the first- and second-stage air ejectors. The shell part consists of the 2 condensers, called the inter- and after-condensers.

The first-stage air ejector element takes a suction on the main condenser and discharges a steam-air mixture into the inter-condenser, where the steam content of the mixture is condensed. The residual saturated air passes to the second-stage ejector element which discharges the air, together with the second-stage ejector motive steam, to the after-condenser of the ejector assembly. The steam content of the mixture is condensed in the after-condenser and the saturated air passes from the ejector assembly through the after-condenser vent to the atmosphere.

The cooling water used for condensing the steam in the inter- and after-condensers of the air-ejector assembly is the condensate that is being pumped from the main condenser to the deaerating feed tank. In order to provide sufficient cooling condensate for the air-ejector assembly during low capacity or standby conditions, a recirculating line is used. (See fig. 7–4.)

The steam condensed in the air-ejector inter- and after-condenser is led back to the feed water system in order to conserve feed water. The drain from the inter-condenser is led back to the condenser through a **U**-shaped pipeline which forms a loop seal. This water seal must be long enough to balance the difference in vacuum between the main condenser and the inter-condenser, so as to prevent noncondensable gases from returning to the main condenser. A drain line is connected from the after-condenser to the fresh water drain collecting tank.

In case of many main air-ejector installations, a gland exhaust condenser is built into the air-ejector assembly. The steam-air mixture removed from the main turbine glands is led into this condenser where the steam content of the gland vapor is condensed and the residual air is discharged to the atmosphere, usually by means of an exhaust fan. The cooling water is the same as used for the air-ejector condensers.

With the gland exhaust condenser built separately, a bypass line is usually installed around the air-ejector condensers for the purpose of bypassing part of the cooling condensate.

Starting

The general procedure for starting an air ejector (fig. 7–4) is as follows:

1. Drain the steam supply line.
2. Start the circulating condensate cooling water through the inter- and after-condensers, and vent the water boxes. Recirculation of condensate will be necessary to provide sufficient cooling water.
3. Open valves in inter- and after-condenser drain lines.
4. Check valves in pressure and vacuum gage lines to be sure they are open.
5. Open first- and second-stage suction and discharge valves of the air-ejector elements to be started.
6. Open wide the second-stage ejector steam inlet valve.
7. When condenser vacuum rises to 20 in. mercury or above, open wide the valve in the steam supply line to the first-stage ejector element.
8. Upon completion of the above procedure, the ejector assembly should be in full operation and the main condenser vacuum should rise rapidly to that usually obtainable under standby conditions.

STARTING PRECAUTIONS.—It should be noted that in starting an ejector the inter-stage valves should always be opened before admitting steam to the ejector nozzles and that steam to the nozzles should always be shut off before closing the inter-stage valves at the discharge of the ejector elements.

Operating

Air ejectors contain no moving parts. Once a unit is properly started, it requires very little attention during operation. It is necessary to provide sufficient flow of cooling water through the inter- and after-condensers, and to main-

tain proper drainage of the inter- and after-condensers and of the steam lines to the air ejector assembly.

Operating personnel are required to know the procedure of shifting air-ejectors elements. This consists of placing the standby unit in operation and securing the operating unit with the ship under way.

Securing

To secure the air ejector assembly:

1. Close first-stage suction valve.
2. Close first-stage steam inlet valve.
3. Close second-stage suction valve.
4. Close first-stage discharge valve (if provided).
5. Close second-stage steam valve.
6. Close second-stage discharge valve (if provided).
7. Leave drain lines open in order that no pressure will build up should a steam inlet valve leak.

Causes of Faulty Operation

Should an air ejector fail to maintain the proper condenser vacuum, the cause may be traced to one of the following difficulties:

1. The steam-reducing valve supplying the motive steam to the air-ejector assembly may not be functioning properly or may be out of adjustment. (Ejectors will not operate properly if inlet steam pressure is less than that for which the nozzles are designed.)
2. Steam strainers are always provided ahead of the nozzles and care should be taken that these strainers are kept clean.
3. Insufficient recirculation of cooling water through the inter- and after-condensers results in loss of vacuum because the circulating water becomes heated to the point where it will not condense the steam entering these small condensers.
4. The thermostatically controlled recirculating valve does not operate properly.

5. Leaks through suction or discharge valves of idle or standby air-ejector elements will result in loss of vacuum through overloading of the operating elements.
6. Leaks in valve glands, gasketed joints, relief or sentinel valves, etc., will result in loss of vacuum.
7. The leakage of tubes or division plate will cause improper operation.

DEAERATING FEED TANK

The major functions of the deaerating feed tank include: (1) provision of a storage reservoir in the feed system to ensure stable operation under rapid fluctuation of load, (2) heating the feed water to a temperature closely approaching that corresponding to the pressure of auxiliary exhaust steam, (3) deaeration of the heated feed water, and (4) maintenance of the reserve supply of feed water in the lower part of the tank in a thoroughly heated and deaerated condition. In the pressure-type deaerating feed system, final reliance is placed on the deaerating feed tank for removal of dissolved oxygen from condensate, drains, and all other feed water components.

In the deaerating feed tank the boiler feed water is heated and deaerated by direct contact with auxiliary exhaust steam. Figure 7–5 shows an arrangement of the type of deaerating feed tanks commonly used in naval installations.

Principle of Operation

The mixture of condensate, drains, and make-up feed water, constituting the inlet water to the deaerating feed tank, enters through the tubes of the vent condenser. The water, being under pressure, is forced through the numerous spray valves and discharged in a fine spray throughout the steam-filled top or preheater section of the tank. The tiny droplets of water are heated and scrubbed by the relatively air-free steam so that nearly all of the dissolved air is released. The drops of water are collected by an inverted conical baffle which conducts them to a central part. Here

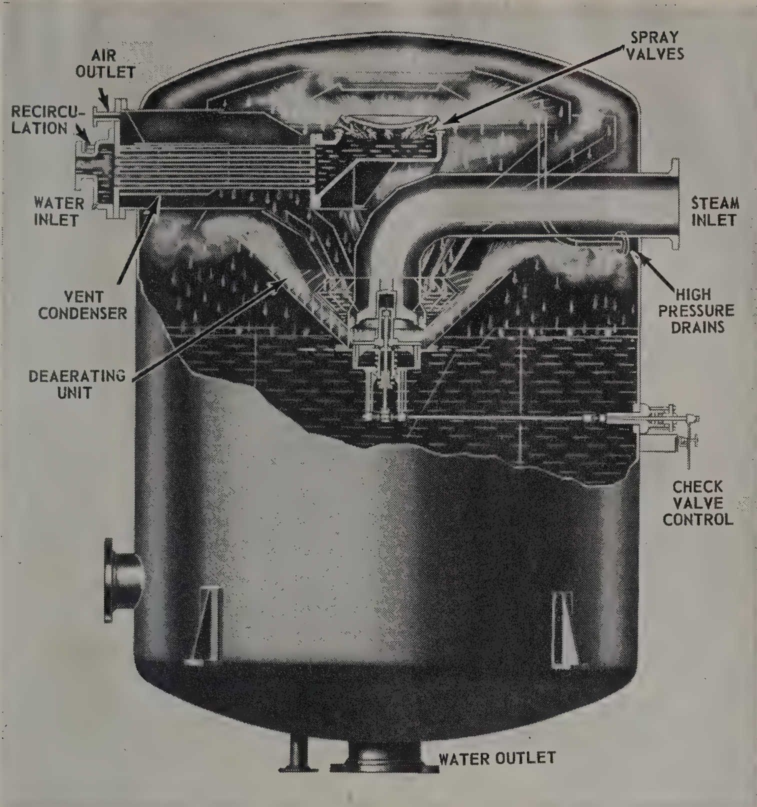


Figure 7–5.—Sectional view of a deaerating feed tank.

the partially deaerated and heated water is picked up by the incoming exhaust steam and thrown radially outward and upward against the lower side of the conical baffle in a finely atomized spray. The water is heated to the temperature of the steam and the dissolved gases removed. The water then falls into the storage space at the bottom of the tank, where it remains under a blanket of air-free steam until needed for the boilers.

The remaining steam which has not been condensed in the tank flows into the shell of the vent condenser, where it is further condensed by heating the incoming water passing

through the tubes. The condensate from the shell of the vent condenser is drained into the conical baffle of the tank. The steam not condensed in the vent condenser flows out through the vent line, carrying with it all of the air which has been removed from the feed water. In most installations, the vent line is led to the gland exhaust condenser and, with an auxiliary branch line, to the after-condenser of the air ejectors of the dynamo plant.

For use when the tank temperature rises too high for normal operation, due to some external condition such as trap blow-by in the high-pressure drain system, a recirculating line is provided leading from the base of the tank into the main condenser. This will provide increased circulation through the tank, and the water will be discharged back into it after being cooled by the condenser, thereby reducing the temperature and pressure within the tank. When lighting off or securing the main plant, it is very frequently necessary to use this recirculating line.

It will be noted that the water inlet header is divided into two compartments. There is a circulation line connection to the upper compartment. Water can flow back through the upper part of the vent condenser and be removed by the recirculation line before it has passed into the tank through the spray nozzles.

Ships equipped with deaerating feed tanks should always carry auxiliary exhaust pressure within the designed range, usually between 10 and 15 psi gage. The exhaust steam inlet valve to the deaerating tank should never be throttled. A connection on the auxiliary steam line is provided to control the exhaust through a reducing valve, as necessary.

MAIN CONDENSATE SYSTEM

There are four general types of feed systems installed aboard naval ships: open, semienclosed, vacuum-closed, and pressure-closed. The old open feed system was replaced by the semienclosed system, with the increase of steam pressure to 400 psi. The next step was to entirely eliminate the free

access of atmospheric air to the feed water by employment of a surge tank vented to main condensers. This arrangement is called the vacuum-closed system. This was replaced by the pressure-closed feed system as steam pressure was increased to 600 psi with 850° F. steam temperature. In this book we will take up only the pressure-closed feed system.

Major Parts of the System

The main condensate system is composed of the following elements: (1) the main condenser hot well, (2) the main condensate pumps, (3) the main air ejectors, (4) the loop seal, and (5) the deaerating tank.

There are two condensate pumps installed for each main condenser. The capacity of each pump is such that either one can be used as a standby. Many of the pumps are of the vertical two-stage centrifugal design. They may be driven by a steam turbine through a reduction gear or by an electric motor. Condensate pumps are usually run at nearly constant speed. The pump will deliver a constant pressure, but its capacity will vary in accordance with the level of water in the condenser. As submergence is reduced the capacity of the pump is reduced. Nearly all condensate pumps have a vent line to the condenser to prevent vapor from being trapped in the pump-suction chamber. It will be noted that these pumps, operating from a vacuum, must have a large suction side below the level of the condenser, so that the pump may receive water by means of gravity. The pump has a water gland sealing line connected from the packing gland to a point in the discharge line beyond the valve. Care must be taken to ensure adequate circulation of water through the pump to prevent overheating.

Piping Arrangement

Figure 7–6 shows a general arrangement of the pressure-closed feed water system.

The main condenser hot well serves as a primary reservoir of condensate. The condensate pump being used pumps

the condensate from the hot well through the air-ejector inter- and after-condensers, the gland exhaust condenser, and the vent condenser to the deaerating tank.

Detailed piping arrangements will vary for the different types of ships. Figure 7–6 gives a general arrangement which does not apply to any particular installation. In nearly all cases the vent condenser is actually a part of the deaerating tank as shown in figure 7–5. In many of the installations the gland exhaust condenser is constructed as part of the air-ejector assembly. Various lines run to the dynamo plant system, which is mostly used during import auxiliary steaming conditions. The cross-connecting lines are used for operating a cross-connected plant and for cross-connecting in case of engineering casualties.

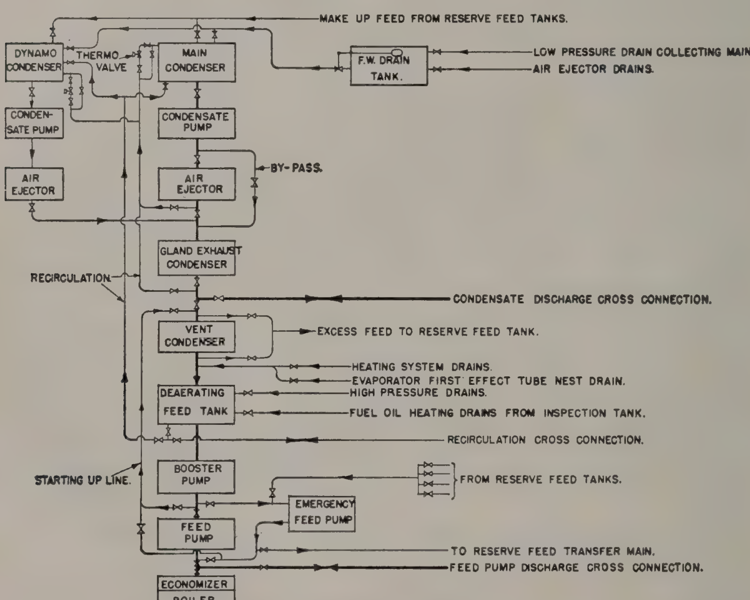


Figure 7–6.—Pressure-closed feed system.

Condensate Recirculation

When warming up a main propelling unit, it is desirable that nearly full vacuum be obtained in the main condenser before any condensate is admitted to the boiler feed system. This may be accomplished by recirculating condensate from the air-ejector discharge line to the main condenser hot well. The water necessary for recirculation is admitted to the main condenser initially through a line from the bottom of the deaerating feed tank to the main condenser. The condensate pumps must be supplied with water at all times while they are operating. Also, the air-ejector condensers must be supplied with cooling water (condensate) before and during their operation. By means of a hand-controlled valve, the thermostatic recirculating valve is bypassed during the warming-up period. When the required condenser vacuum is obtained, the manually controlled bypass valve is closed when the valve in the condensate line beyond the air ejectors is opened to cut the condenser into the feed system.

The bypass valve around the thermostatic valve is for use when warming up the plant. It is also provided for use in case the thermostatic valve fails to operate properly. Under normal operating conditions, recirculation to the main condenser at light loads is automatically controlled by the thermostatic recirculating valve. In many installations two sources are provided for recirculation, one from the recirculating connection on the vent condenser in the deaerating tank (as indicated in the discussion of that tank) and the other from the condensate discharge line beyond the air ejector. Both of these lines lead to the thermostatic and manual control valves. The connection beyond the air ejector is used with the manually controlled valve during the warming-up period. The connection to the vent condenser in the deaerating tank is used when under way, with the thermostatic valve in operation.

Warming Up the Deaerating Tank

It is important that a secured deaerating feed tank be kept isolated from the system and its contained water

deaerated before the tank is cut into the system to supply boiler feed water. If the secured tank is empty, it may be filled by means of the emergency feed pump taking suction from a reverse feed tank and discharging through the starting-up line, indicated in figure 7–6, to the main condensate line just ahead of the vent condenser. During this operation auxiliary exhaust should be supplied to the deaerating feed tank in order that the incoming water will be heated and deaerated. The steam valve should be opened slowly in order to avoid sudden temperature changes within the tank. When the tank is filled up to the normal operating level, a feed booster pump should be employed to circulate the heated water from the bottom of the tank back through the vent condenser via the starting-up line for about 10 minutes, to insure complete deaeration of the water.

If the secured deaerating tank is not empty, it may be warmed up by use of a booster pump in connection with the starting-up line for recirculation of the contained water. Auxiliary steam is supplied to the tank during recirculation, and the water is gradually heated and deaerated.

When the deaerating tank is fully warmed up, the valve in the starting-up line should be closed where the small (5 percent of capacity) recirculating line is used to protect the booster pump. Otherwise, the starting-up line valve must be throttled until the main feed pump has been started so that its recirculating line can be used.

Water Level Control

The water level in the deaerating tank is controlled by means of the make-up and excess-feed valves.

Make-up feed is admitted to the main condenser as necessary through the make-up feed line connecting with the reserve feed tanks. The action of the vacuum in the condenser will draw the water from the reserve feed tank into the condenser. Precautions should be taken to ensure that there is sufficient water in the reserve feed tank because if the reserve tank should become empty, a loss of vacuum would re-

sult in the main condenser, when attempting to take on make-up feed water.

Excess feed is normally discharged to reserve feed tanks from the main condensate line beyond the air-ejector assembly or beyond the gland exhaust condenser.

When the water level in the deaerating tank becomes low, the make-up feed valve is opened to bring the water level up to the normal operating condition. Similarly, when the water level is too high in the deaerating tank the excess-feed valve is opened to bring the level down to normal. Sufficient capacity is provided in the storage section of the deaerating tank so that the discharge of excess feed or the admission of make-up feed should be unnecessary when the ship is maneuvering. If the water level becomes too high the deaerating tank will not function properly and the water will not be deaerated. If the deaerating tank becomes dry it will cause a serious casualty to the main feed pumps and a possible casualty to the boilers, because of low water. Emergency procedures must be taken when the water level in the deaerating tank becomes too low for safe operation.

High-Pressure Drains

High-pressure drains are collected by the high-pressure steam drainage main and are discharged directly to the deaerating feed tank. Oil heating drains are collected by the oil heating drainage main and are led to a drain inspection tank where oil contamination can be detected. Clean drains are discharged from this tank to the deaerating feed tank. Contaminated drains are discharged to the contaminated drainage main, if installed, or to the bilge.

Low-Pressure Drains

Low-pressure drains are collected by the fresh-water drain-collecting main and are led to the fresh-water drain-collecting tank. Generally, float-controlled pumps are provided to discharge the drains collected in this tank to the condensate discharge system ahead of the deaerating feed

tank. When pumps are not provided, drains are taken into the condensate system via vacuum drag lines to the main and/or auxiliary condensers. A float-actuated valve is provided in the vacuum drag line, and is adjusted to maintain a minimum level in the drain tank, to prevent loss of vacuum. The evaporator first-effect tube nest drains are usually discharged by a pump to the condensate discharge system.

MAIN FEED WATER SYSTEM

The function of the main feed water system is the pumping of feed water from the deaerating tank to the boilers. The system consists of the necessary pumps and piping to accomplish this purpose. The feed water system can be broken down into three parts or systems: the main feed booster system, the main feed system, and the emergency feed system. The main booster system is that part of the feed system in which water flows from the deaerating tank through the main feed booster pumps and up to the suction of the main feed pumps. The main feed system carries water from the main feed pumps to the boilers. The emergency feed system is that part of the main feed system through which water can be supplied to the boiler from a reserve feed tank by means of the emergency feed pump. It can also be used for other purposes, such as transferring feed water and auxiliary in-port steaming.

Main Feed Booster Pump

The feed booster pumps take suction from the deaerating tank with the water at or near the temperature equivalent to the suction pressure and, like condensate pumps, are designed with suction and vent connections of liberal size. These pumps are of the centrifugal type, and many of them are of the vertical design. Unlike condensate pumps the feed booster pumps usually work under a liberal submergence head of six or more feet. Feed booster pumps usually operate at or near constant speed. They are driven by a steam turbine or an electric motor. The turbine is controlled by a speed-limiting governor.

A vent connection is provided from the suction casing of the pump leading back to the deaerating tank. Operating the pump with this vent connection open at all times will tend to prevent the pump from becoming vapor bound.

A small recirculating line is provided to ensure against operation of the pump without flow of water through it. This line is designed to bypass 5 percent of the capacity of the pump. The recirculation line leads from the discharge line of the booster pump to the deaerating tank. The recirculating line should be open during warming up of the main feed pump. When the main feed pump is put on the line, discharging to the boilers, the valve on the recirculating line for the booster pump should be closed. The open recirculating line for the main feed pump, later discussed, will provide sufficient flow through the main booster pump should feed be suddenly stopped. It is desirable to leave the recirculating line open when the main feed booster pump is discharging to the emergency feed pump since the latter, being a reciprocating pump, will take a varying suction from the booster pump.

There is a recirculating line which usually leads from the booster pump discharge piping to a point in the main condensate piping beyond the air-ejector assembly. This connection is normally called the starting-up line. It is used to warm up a cold deaerating tank, as previously described. Under no circumstances should the large starting-up line valve ever be allowed to remain open when a main feed pump is operating. This might reduce the main feed pump suction pressure below the designed limit and thereby cause a casualty to that pump.

Main Feed Pumps

Most of the main feed pumps are of the high-speed, multistage, horizontal, turbine-driven, centrifugal type. The pumps are designed for parallel operation. In the pressure-closed feed system, the feed booster pump maintains a pressure high enough to prevent vapor binding or flashing when the feed water is at a temperature above 212° F. A vent connection is provided to the suction chamber of the feed

pump. When the pump is first started, this first-stage vent should always be open to carry away any accumulation of air or vapor which may be trapped in the pump casing. The vent stop valve should normally be closed when the feed pump is operating.

To provide continuous circulation through the pump, a recirculating line is provided leading from the pump discharge connection to the deaerating tank. An orifice is placed in the line to limit the amount of water recirculated to 5 percent of the capacity of the pump.

Under normal operation the turbine-driven centrifugal boiler feed pumps are operated at variable speed, the speed being adjusted automatically by pump-pressure governors. If the pump-pressure governors fail or are cut out and hand throttling of steam to the turbine is not resorted to, the pumps will operate at constant speed on their turbine speed-limiting governors. The reason for this is that when the pump-pressure governor is set to give a discharge pressure above the designed pump pressure, the governor valve is forced wide open and no longer controls the pump speed; the turbine speed-limiting governor then comes into action to hold the speed of the unit constant at or near rated speed.

All turbine-driven units are fitted with a speed-regulating or speed-limiting governor and an overspeed trip. If governors are properly set, the turbine speed will at no time exceed the rated speed by more than 5 percent. If governors do not function within the above limit, they should be overhauled and the cause of faulty operation located and remedied.

Whether the above-mentioned governors be hydraulic speed-limiting governors, hydraulic pressure governors, or the geared centrifugal fly ball type, it is essential that the overspeed trip be set to trip out the unit when rated speed is exceeded by 10 percent. For satisfactory parallel operation of boiler feed pumps it is essential that the governors of all identical pumps be set for the same speed.

The main feed piping system is designed so that it will be flexible, which means that different set-ups can be used.

Where practical, a loop system is installed. Arrangements are made so that the system can be split or cross-connected. Also, various combinations of pumps can be used and certain sections of the systems can be isolated. The purpose is to provide means of overcoming or minimizing battle damage or engineering casualties.

Emergency Feed Pumps

Reciprocating emergency feed pumps are installed as a source of supply of boiler feed water in emergencies. When the ship is under way, these pumps should always be kept warmed up in standby condition, and with suction on one of the reserve feed tanks. In the event of unexpected loss of the normal boiler feed water supply, due to a feed pump derangement or other cause, emergency feed pumps are immediately started, taking suction direct from a reserve feed tank and discharging through the economizers to the boilers to avoid a boiler casualty.

The emergency feed pump is normally arranged to perform several important functions in addition to its primary function of supplying water to a boiler in an emergency. Many ships are not provided with port-use feed pumps and the emergency feed pump is normally used to handle boiler feed water in port, taking suction from the main booster line. Distribution of reserve feed water among reserve feed tanks is another function of the pump and piping system. It is also employed to pump out the boilers by use of portable hose lines. The emergency feed pump is used sometimes for filling the deaerating tank, by means of the starting-up line.

MAIN STEAM SYSTEM

The main steam system is the piping system which leads the steam from the boilers to the main turbines. Although one of the most important, the main steam system is the simplest piping system on board ship. It will vary according to the type of ship. The system is arranged to allow for either cross-connected or split-plant operation of fire-

rooms and enginerooms. An attempt is made to provide the maximum flexibility and protection against the effects of battle damage and yet keep the system as simple as practicable. Provisions are made for the expansion and slight movement of the large steam lines by means of expansion bends. The piping is supported by means of hangers. The constant support and the variable spring type of pipe hangers are used. Because of the high temperatures, a large amount of insulation and lagging is provided for main steam lines.

Warming Up the Main Steam Line

The main steam line must be warmed up slowly to prevent leaks at the joints and must be carefully drained to prevent all danger of water hammer. The steam line should be warmed up by opening bypass valves, and drained by making certain that the drains to the trap line are open and that the traps are functioning properly. When the boilers are cut into the main line, the stop valves must be opened carefully and slowly.

When the main steam lines are being warmed up prior to getting under way, full pressure must not be on the main steam line up to the throttles. The preferred method is to warm up the main steam line to the bulkhead stop. Then by use of the bulkhead stop bypass, build up pressure in the main throttle lines. Before you open the valves connecting the boilers to steam piping or connecting different sections of steam piping, the bypass valves should be opened first, the piping warmed, and the pressures equalized before the larger valves are opened. Under way, special precautions must be taken when placing additional boilers on the superheated main steam line. The superheat temperature of the line must be nearly equal to the steam temperature of the incoming boilers when they are cut into the main steam line.

The greatest care should be exercised to guard against water rams in steam piping; before steam is admitted, all sections and other spaces where water might accumulate must be carefully drained. When steam is about to be ad-

mitted to a section of piping, open the trap bypasses to ensure free drainage. When certain that the piping is free of water, close the bypasses to prevent live steam from being blown through. Watch the steam lines during the process and set up on any leaky joints. Main steam line hangers should be checked periodically to see that they are functioning properly.

Low Steam Pressure

When running at high speeds, or during certain engineering casualties, if the steam pressure drops for any reason, demands for steam must be cut down decidedly and without hesitation, until the pressure begins to build up. Otherwise the blowers, pumps, and other vital auxiliaries upon which depends the supply of more air, fuel, and electric power will slow down, causing a drop in pressures and loss of electric power. Ships have been known to have been brought to a full stop with all fires out, as the final result of bleeding the steam from the system by keeping the main engine throttles open. Unless a boiler is to be secured, at no time should the steam pressure be allowed to fall below 85 percent of the authorized boiler working pressure.

Connections Between Boilers and Steam Lines

Under ordinary conditions the saturated steam load of a vessel with superheat control boilers should be divided among all the boilers in use. Before any boiler—or combination of boilers—is cut in on the main steam line, it should first be cut in on the auxiliary steam line. That is, if two boilers in the same fireroom are both furnishing steam to the main steam line, the valve in the auxiliary steam line between those two boilers must be open; similarly, if the cross-connection in the main steam line between the port and starboard engines and/or between the forward and aft enginerooms is open, the corresponding connection(s) in the auxiliary steam line must also be open. Otherwise, an increase in the saturated steam load on one boiler (or group of boilers, as the case may be), without a corresponding increase

in the firing rate on the saturated side of the boiler(s) concerned, will cause a drop in drum pressure, and may cause stagnation or reversal of flow through the superheaters of those boilers with consequent overheating of the superheaters. The cross-connection in the auxiliary steam line should be opened before the cross-connection in the main steam line.

Ship's service generators are operated on steam taken through the superheater of a boiler, regardless of whether or not the superheater is being fired. This practice affords the maximum protection to the superheater. In ships not fitted with separate generator steam lines direct from the superheater outlet or desuperheaters, a section of the main steam line is used for this purpose.

LUBRICATION SYSTEMS

The essential parts of a forced-lubrication system are as follows:

PUMPS for delivering the oil to the various parts of the system.

OIL SUMP TANKS to which the oil is led after having passed through the bearings and gears of the system.

OIL COOLERS through which the oil passes on its way to the system.

OIL-SETTLING TANKS in which the water and other impurities are allowed to settle and in which used oil is stored.

OIL STRAINERS for removal of foreign matter from the oil before it enters the bearings and oil sprays.

OIL PURIFIERS, which are used to remove all water and other impurities from the oil.

OIL HEATERS, which are used to raise the temperature of the oil entering the centrifugal purifier to facilitate removal of water.

PIPING, GAGES, THERMOMETERS, and other instruments used to indicate the operating conditions of the system.

Operation of Oil Pumps

Two lubricating oil pumps are provided for each system. Many ships are equipped with an additional main lubricating

oil pump in each engineroom, chain-driven from the main shaft. The pumps are of the positive displacement rotary design. Only one pump is used at a time, the other being warmed up and ready for instant use in case of failure of the pump on the line. The pumps are so interconnected that in case of failure of the one in use, the other will start automatically. The chain-driven pumps are arranged to furnish the primary supply of oil to the bearing and gear headers at high speeds, with one of the other pumps as standby. At low speeds the steam-driven oil pump will furnish the primary supply of oil, which is augmented by the supply from the chain-driven pump. The chain-driven pump is also interconnected so that it will take over supply at high speeds and the regular pump in use will become the standby pump. When the ship slows down to a low speed, the steam pump will cut in and take over the supply of oil.

A pressure-operated warning signal system is installed at the lowest point of the discharge side of the system. This signal is set at a predetermined minimum pressure and operates to give the throttleman instant warning of low oil pressure. A weight-loaded relief valve is also installed, which discharges into the sump tank whenever excessive oil pressure is built up.

Where the turbine-driven lubricating oil pump is fitted with a constant pressure governor the starting procedure should be carried out with the governor bypassed. Upon satisfactory operation of the pump the governor should be cut in and adjusted to give the required pump discharge pressure. The use of automatic control devices does not relieve the operating personnel of the responsibility of checking frequently during each watch to see that all is normal.

Cooling the Oil

The amount of circulating water to be passed through the oil cooler depends upon the temperature of the cooling water, the cleanliness of the lubricating oil cooler, and the quantity of heat to be removed from the lubricating oil to

maintain proper bearing temperatures. If the temperature of the injection water is low, a smaller amount of circulating water is necessary to cool a given quantity of oil a certain number of degrees than is necessary with injection water at a higher temperature. As soon as the temperature of the oil leaving a bearing or unit becomes higher than that considered satisfactory, the temperature of the oil should be decreased by increasing the quantity of circulating water through the coolers. This is accomplished by manipulation of the valve in the overboard discharge from the cooler.

The salt water side of an oil cooler should be kept drained if it is not to be used within 24 hours.

Operation of Purifiers

Centrifugal purifiers are provided in the lubricating oil system to permit removal of water and impurities not removed by the strainer. There are two methods that can be used in purifying lubricating oil—batch purification and continuous purification. In the batch process, the oil is transferred from the sump to a settling tank. The oil is heated in the settling tank and its temperature is maintained at approximately 160° F., but not exceeding 180° F., for several hours by means of the steam-heating coils installed. Water and other settled impurities are stripped from the settling tank through a drain valve. The oil is then centrifuged and discharged to the sump from which it was taken. In the continuous purification process, the centrifugal purifier takes suction from a sump tank and after purifying the oil, discharges it to the same sump. This process is normally employed while under way. Particular care must be taken to ensure return of all the oil to the engine sump from which it is being taken.

Periodic tests should be made to ensure that the purifier is working properly. The tests should be made at intervals of about 30 minutes when the oil in a system is being renovated. Under way, when continuous cleaning is the proper procedure, the tests should be made once during each watch.

Oil for analysis may be drawn from the sampling cocks. The general efficiency of the purifier may be determined by observing the clarity of the cleaned oil, and the amount of oil in the separated water.

Proper care of an oil purifier requires that the bowl be cleaned frequently and all sediment carefully removed. Some lube oil purifiers are equipped with clarifying ring dams (in addition to purifying ring dams) for clearing the oil of solid impurities.

Preparing System for Use

Before the system is put into operation, steps should be taken to ensure that all parts of the system are in efficient condition and that the oil is free of impurities. To do this, drain an oil sample from each drain tank, carefully note and record the readings of the oil level indicators, and examine and clean all strainers.

To put the system into operation, start an oil service pump in each system, circulate the oil and maintain a steady average service pressure at all bearings of the main engines. Each duplicate lubricating oil service pump should be tested, using automatic controls if fitted. Main lubricating oil pumps should be operated on their pressure regulators, if fitted. The oil should be circulated at least one hour before getting under way.

The temperature of oil supplied to reduction gears must be at least 90° F. before units are turned over. If the oil is below this temperature, it should be heated to 100° F.

Ensure that the oil-cooler circulating water system is in satisfactory operating condition. Inspect all bearings carefully to ensure that there is an ample supply of oil at each bearing and that there are no leaks.

Inspect the oil-cooling system for leaks, and test the low-pressure alarm by decreasing the oil pressure until the alarm sounds. If the alarm is inoperative, remedy the defect at once.

Sample the oil to see whether water has collected in the system. To ensure against leakage of salt water into the oil

through leaky coolers, never cut in the coolers until after the oil pumps have been started and always secure coolers before securing oil pumps.

Operation of Lubricating Oil System

Too much stress cannot be laid on the vital importance of proper lubrication of all units in any machinery plant. All rubbing surfaces must receive a steady and sufficient supply of oil of the proper quality at the proper temperature; and, as impurities are continually getting into the system, means must be provided for removing these impurities from the oil. In addition, an adequate reserve supply of clean oil should always be maintained.

The pressure to be carried at the various parts of the lubrication system differs with the type of installation. To avoid flooding of bearings and foaming of oil, excess pressures should not be used.

The lubricating oil temperature from the bearings should be maintained at 140° to 160° F., insofar as practicable, but must not be allowed to exceed 180° F. The maximum allowable temperature rise through the bearings shall not exceed 50° F., even though the maximum temperature of 180° F. is not exceeded. An excessive temperature rise indicates that something is wrong with the bearing and that it should be investigated.

Every bearing has a normal running temperature, which should be known and observed. Any rise above this normal temperature should be satisfactorily accounted for, the bearing watched carefully, and a remedy applied. Until a remedy is applied, the machinery should be slowed, or stopped as necessary, to avoid exceeding safe bearing temperatures.

In many cases thermometers give only the average temperature within the bearing reservoir. For this reason, a check must be made by feeling the cap and by inspecting the sight glasses to ensure a positive flow of oil.

Strainers should be removed and cleaned once each watch (or when a pressure drop of 1–1½ psi above normal is noted

through the strainer), and the residue found therein must be examined carefully. If pieces of metal are found, determine the character of this metal. Bits of brass or babbitt metal indicate either that there is a damaged or wiped bearing in the system or that the bearing metal is breaking up. In any case, the bearings should be examined. If the metal has the appearance of iron rust, it indicates that corrosion is occurring in the system and that the rust is flaking off. If this condition exists, the system must be cleaned and scraped at the earliest opportunity, as pieces of metal rust will scratch the bearing or mar a thrust shoe, especially in a Kingsbury thrust bearing. A sudden rise in bearing temperature, followed by a return to normal condition, generally indicates that some foreign substance reached the bearing, scratched it, and was then washed away by the oil supply.

Every precaution should be taken to prevent the entry of water into the lubrication system, and every effort must be made to effect its immediate removal when it is present. Water in the oil not only increases the frictional resistance and causes the oil film to break down prematurely, but also corrodes the journals. Furthermore, the presence of water in the oil may cause corrosion in the entire system, particularly in those parts which are not covered by oil at all times.

When coming to anchor and when securing the main propulsion machinery, oil must be circulated through the turbines and reduction gear lubrication system by means of the ship's oil pumps for a period of at least one hour in order to minimize the effects of an unavoidable amount of fresh-water condensation. The motor-driven shaft turning gear, if provided, is to be operated during this 1-hour period.

Water enters the lubrication system at the following principal points: (1) at leaky tubes or joints in the oil coolers, (2) at the steam-sealed glands of turbines, (3) through vents on tanks and gear casings, as atmospheric moisture which is subsequently condensed, and (4) through leaks in drain or sump tanks located in the bilges.

In lubricating-oil systems there are two kinds of leaks en-

countered—oil leaking from the system, and water leaking into the system. Leaks of oil from the system can be detected by an increase in the oil consumption, by the presence of oil in the bilges, and by noting the flow of oil at the faulty part. Leaks of water into the system can be detected by testing the discharge from the drain tanks and settling tanks and noting the character of the discharge from the purifier, and by an increase in the reading of the gages attached to the drain tanks.

In order that leaks of any kind may be readily detected, the following inspections should be made:

1. Hourly, note and log the amount of oil in the drain tanks.
2. Daily, open the test cock on the water side of the oil cooler and note whether there is any oil in the cooling water.
3. Frequently inspect the bilges for the presence of oil.
4. Frequently inspect the bearings, oil lines, and fittings for leaks.
5. After getting under way, carry the oil at the proper height in the drain tanks to avoid loss of oil by overflowing.
6. During each under way watch, inspections are made frequently to ensure that the float gage on the drain tank is operative.
7. Just before a watch is relieved, all oil cups, manifolds, and cans are filled to the working level and the reading of the storage tank is taken.

Ordinarily, lubrication systems are operated as separate and distinct systems with the cross-connection valves closed. Necessary standby lubricating oil pump(s) must be kept warmed up and ready for instant use in case of failure of the pump(s) in operation.

Interruption of Oil Supply to a Bearing

The flow of oil as observed through the sight glasses fitted in the oil-discharge lines at the bearings must be uniform.

Frequent inspections must be made during each watch, in order that any interruption in the oil supply to a bearing may be detected immediately. If the oil supply to a bearing is interrupted or the pressure drops below normal for one or more bearings, carry out the same procedure as discussed under the heading "MAIN TURBINE—Loss of Lubricating Oil Pressure." It is imperative that oil sight glasses be kept clean and in good condition at all times.

Procedure When Oil Pressure Suddenly Increases

If a sudden increase in the oil pressure at the pump is noted, the flow of oil at the bearings must be inspected immediately and steps taken to locate and remedy the trouble. When this condition arises, it will generally be found that the trouble is due to a clogged strainer or pipeline.

Care of Lubricating Oil System

Lubricating oil may lose its lubricating qualities if it is contaminated, but if the impurities and water are removed as soon as their presence is noted, the oil can be used indefinitely.

Clean oil must be pumped through the system for at least 15 minutes every day when not under way. This should be done at the same time that the main engines are jacked over.

Every steam-driven ship with forced lubrication equipped with centrifugal-type lubricating oil purifiers must operate the purifier each day while under way until there is no visual indication of water in the oil. It is estimated that at least 12 hours' operation daily, preferably intermittently during a 24-hour period, will be necessary to accomplish this. On securing the main propulsion machinery, the lubricating oil must be purified until no water is discharged from the purifiers. Furthermore, approximately once a month or after each extended operation, all oil in the lubrication system must be pumped to the settling tanks and renovated, at which time sumps and drain tanks should be inspected and wiped down.

Owing to the importance of lubrication in its relation to the efficient maintenance of machinery, and to avoid prevent-

able casualties due to lack of proper lubrication, all ships make up lubrication charts for each machinery unit and system on board. These charts are kept posted in machinery spaces.

The pressure gages on the lubrication system must be tested quarterly. As frequently as operating conditions permit, all oil is pumped from sump tanks, the manhole plates lifted, and the interior of the tanks examined. Routine inspection is made after each extended operating period—monthly when there is intermittent steaming, and quarterly at anchor. If any sludge or other impurities are detected, the tank must be cleaned before the system is again put into operation.

SELF-OILING BEARINGS

Certain types of machinery are supplied with self-oiling bearings, consisting of an oil well below the journal, and oil rings or chain loops which are rotated by the shaft. The lower parts of the oilers are immersed in the oil in the well and as they rotate they continuously supply lubrication to the bearings.

Oil rings which do not have smoothly finished, truly circular, inside circumferences will hang and fail to rotate evenly, or perhaps fail to revolve. A slight imperfection on the inside surface of a ring will result in insufficient lubrication. If an oil ring does not revolve evenly, it should be examined for defects. Oil rings must be installed on the correct side of their wipers so that the desired quantity of oil will be carried up to and wiped from the top of the journal. When oil rings are first installed or repaired, care must be taken that they do not drag or hang up on the bottom or sides of the adjacent bearing structure.

Chain oilers have the advantage of being more easily removed and replaced than are ring oilers, but they are more subject to wear and subsequent breakage. They should be inspected and renewed when evidence of weakness is found. When renewal is made, care should be exercised that the new chain is not so long that it drags on the bottom of the oil well.

Oil must always be carried at a depth sufficient to give the oilers proper immersion. Most oil wells carry maximum-minimum marks to show the proper level. Under way, the oil level and bearing operations must be inspected hourly.

QUIZ

1. At what point in the basic steam cycle is the thermal energy of steam converted into mechanical energy, or work?
2. What arrangement of the piping systems provides the maximum resistance to battle damage?
3. What are the five basic requirements for naval boilers?
4. Under normal conditions, how long a time should be allowed for lighting off and cutting in a boiler?
5. What is the correct sequence to follow when cutting in burners to meet a demand for increased speed?
6. When superheat control boilers are to be secured, what procedure is followed as far as the superheater side is concerned?
7. Whenever possible, what is the first thing to be done in cases of engineering casualty?
8. What is usually the cause of low water in the boiler?
9. What should be done BEFORE attempting to determine whether a boiler casualty is caused by low water or by high water?
10. When the suction of the fuel oil service pump is lost, how much of the available steam should be directed to the service pump?
11. As far as possible, what are the first two steps to be taken in case of a large steam leak in a boiler?
12. What precaution should be taken to prevent turbine distortion and damage during warming up of the main turbines?
13. At what point in warming up the main turbines must the lubrication oil system be placed in operation?
14. When warming up, why is it preferable to spin the astern turbines before spinning the ahead turbines?
15. What would be the most likely source of difficulty in a turbine which suddenly begins to vibrate abnormally and to make a rumbling noise?
16. If a turbine or reduction gear bearing is overheating because of local loss of oil, why should the turbine be slowed down but NOT stopped until it has cooled down?
17. In terms of the efficiency of the total installation, why are reduction gears necessary?

18. A slight jarring or vibration which may be noticed in the reduction gear case is considered to be normal under certain conditions of operation. When is this likely to occur?

19. What are the two functions of condensers?

20. Why is it that air in any part of the steam system will eventually flow to the condenser?

21. What three independent means for checking condenser vacuum are found on almost all ships?

22. What is the purpose of the recirculation piping system of the condenser?

23. What is the effect on a condenser of air leakage, improper air removal, flooding, improper condensate drainage, or an insufficient supply of circulating water?

24. How frequently must the condensate from each main condenser be tested for salinity?

25. After an air-ejector unit has been properly started, what attention is necessary to keep it in operation?

26. In the pressure-type deaerating feed system, at what point is the dissolved oxygen finally removed from all feed water components?

27. When warming up, how is the necessary vacuum obtained in the main condenser?

28. What must be done to the water contained in a deaerating feed tank, before the tank is cut into the system to supply boiler feed water?

29. What valves are used to control the water level in the deaerating tank?

30. Why should the starting-up line valve never remain open when a main feed pump is operating?

31. In the pressure-closed feed system, how is the feed pump suction pressure increased so that the feed pumps are able to handle the hot water from the deaerating tank?

32. What special precautions must be taken when additional boilers are being placed on the superheated main steam line?

33. What is the purpose of operating ships' service generators on steam taken through the superheater of a boiler, even if the superheater is not being fired?

34. At high speeds, which pumps furnish the primary supply of lubricating oil to the bearing and gear headers?

35. What three factors primarily determine the amount of circulating water which must be passed through the lubricating oil cooler?

36. Which method of purifying the lubricating oil is normally used while the ship is under way?

37. In checking the temperature of lubricating oil from the bearings, why is it not possible to rely entirely on thermometer readings?

38. While a ship is under way, how long a time is required for complete purification of the lubricating oil by the centrifugal type purifiers?

39. Compare the relative advantages of chain oilers and ring oilers.

CHAPTER 8

REFRIGERATION

From your previous study and experience you should be familiar with the basic theory of refrigeration and have an understanding of the mechanical refrigeration cycle. If you need to refresh your memory on these points, study again the section on refrigeration in the Navy Training Course, *Fireman*, NavPers 10520.

In order to make the rating of MR1 or MRC, however, you will need to know a great deal more about refrigeration. You must know how each of the component parts of the refrigeration plant functions, how the equipment is operated, and how it is kept in top operating condition. These points are discussed in this chapter.

BASIC FREON–12 REFRIGERATION SYSTEM

You will recall that the four essential parts of a refrigeration system are (1) the evaporator (cooling coil), where the refrigerant absorbs heat and boils to a gas, (2) the compressor, where the refrigerant gas is compressed, (3) the condenser, where the latent heat of the gas is given up and carried away by the cooling medium, thereby changing the gas to a liquid, and (4) the expansion valve through which the pressure of the refrigerant liquid is reduced so that the refrigerant can repeat its process of absorbing heat in the evaporator. Figure 8–1 shows the arrangement of the parts and connecting piping of a basic type refrigeration system.

From the orifice of the expansion valve, through the evaporator, up to and including the intake side of the compressor cylinders is called the LOW-PRESSURE SIDE. (The dividing line between the low- and high-pressure sides is the discharge valve of the compressor.) The remainder of the system from the discharge valve of the compressor through the condenser, receiver, and expansion valve to its orifice is called the HIGH-PRESSURE SIDE. (The dividing line between the high- and low-pressure sides is the thermostatic expansion valve.)

The refrigeration plants installed on naval vessels vary in detail of arrangement, construction, operation, and maintenance, depending upon the purpose for which refrigeration is required and the type of refrigerant employed. Among the refrigerants commonly used are Freon–12, Freon–11, Freon–22, and ammonia. Since Freon–12 is the refrigerant used most extensively on naval vessels, the remainder of this chapter deals specifically with the Freon–12 plant.

Refrigerant

Freon–12 is the direct result of a search for the perfect refrigerant and more nearly approaches the ideal than any

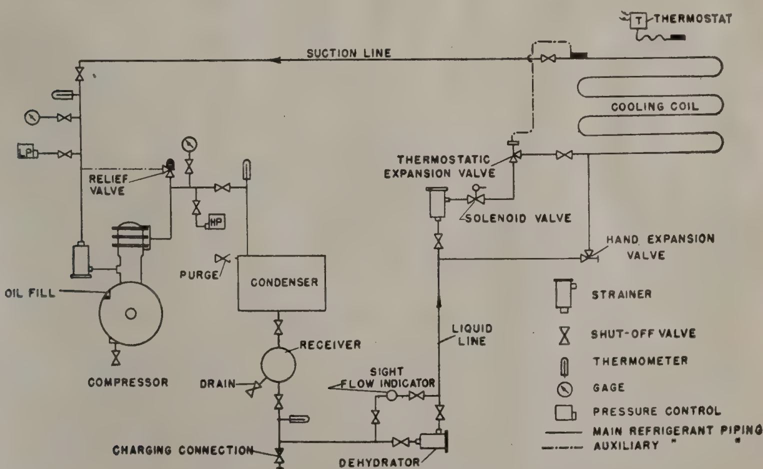


Figure 8–1.—Basic refrigeration system.

other thus far discovered. Its chemical name is dichlorodifluoromethane, and its chemical formula is CCl_2F_2. In the manufacture of Freon–12, fluorine is substituted for part of the chlorine in carbon tetrachloride. This substitution has the remarkable effect of lowering the boiling point by 120 degrees. At atmospheric pressure, Freon–12 boils at $-21.66°$ F. and solidifies at $-252°$ F. Its latent heat of vaporization at atmospheric pressure is about 72 Btu per pound.

Generally speaking, Freon–12 may be considered the safest refrigerant yet developed for use on board ship. It has the following advantages: it is nonflammable, nonexplosive, and noncorrosive; its vapor is nontoxic except when decomposed by a flame at high temperatures (1022° to 1382° F) ; it will not harm food; it is odorless in concentrations of 20 percent or less by volume (in higher concentrations, it has a slight odor of carbon tetrachloride) ; and it is tasteless.

Nonetheless, there are certain SAFETY PRECAUTIONS that must be observed in handling Freon–12. Since this refrigerant is practically odorless and nontoxic, it will not be necessary to wear a gas mask when servicing Freon–12 equipment. It is essential, however, that goggles or large lens spectacles be worn, to eliminate the possibility of liquid Freon–12 coming in contact with the eyes and causing injury by freezing the moisture in the eyes. This protection is necessary and should be taken whenever loosening a connection in which Freon–12 liquid may be present!

If liquid Freon–12 comes in contact with the eyes, the person suffering the injury should be taken at once to the medical officer; avoid rubbing or irritating the eyes. First aid treatment should be given as follows:

1. Drops of sterile mineral oil should be introduced into the eyes as an irrigant.
2. If irritation continues, the eyes should be washed with either weak boric acid solution or sterile salt solution containing not more than 2 percent sodium chloride.

Should liquid Freon–12 come in contact with the skin, the

injury should be given the same treatment as though the skin had been frost-bitten or frozen.

Should a person be overcome in a space which lacks oxygen because of the high concentrations of Freon–12, he should be given the usual treatment for suffocation—i. e., artificial respiration.

Evaporator

The evaporator is nothing more than a bank or coil of copper tubing installed inside a refrigerated space. The coils for the cold storage spaces are usually mounted flat on the sides of the compartment. They are attached to the walls by clips and brackets which hold them away from the box lining to permit circulation of the air around the coils.

Air is used as a secondary refrigerant to carry heat from the food storage spaces to the cooling coils. Electric fans discharge at overhead level to augment the circulation of air and minimize dead pockets. To further ensure free circulation of the air being cooled, battens are provided in front of the cooling coils, and should be used between the stored food boxes.

Suction Pressure Regulating Valves

Suction pressure regulating valves may be installed in the suction line (1) at the outlet of the evaporator where a minimum temperature must be maintained (as in fruit and vegetable rooms), or (2) where two or more spaces serviced by a single compressor unit are maintained at different temperature levels. These valves are designed to maintain, within the cooling coil, a substantially constant pressure which is higher than the suction pressure downstream and independent of suction pressure fluctuations. Figure 8–2 shows a cross-sectional assembly view of a typical suction pressure regulating valve.

Valve adjustment is obtained by compression of the adjusting spring to a point where a predetermined coil pressure is established. Automatic operation is maintained by

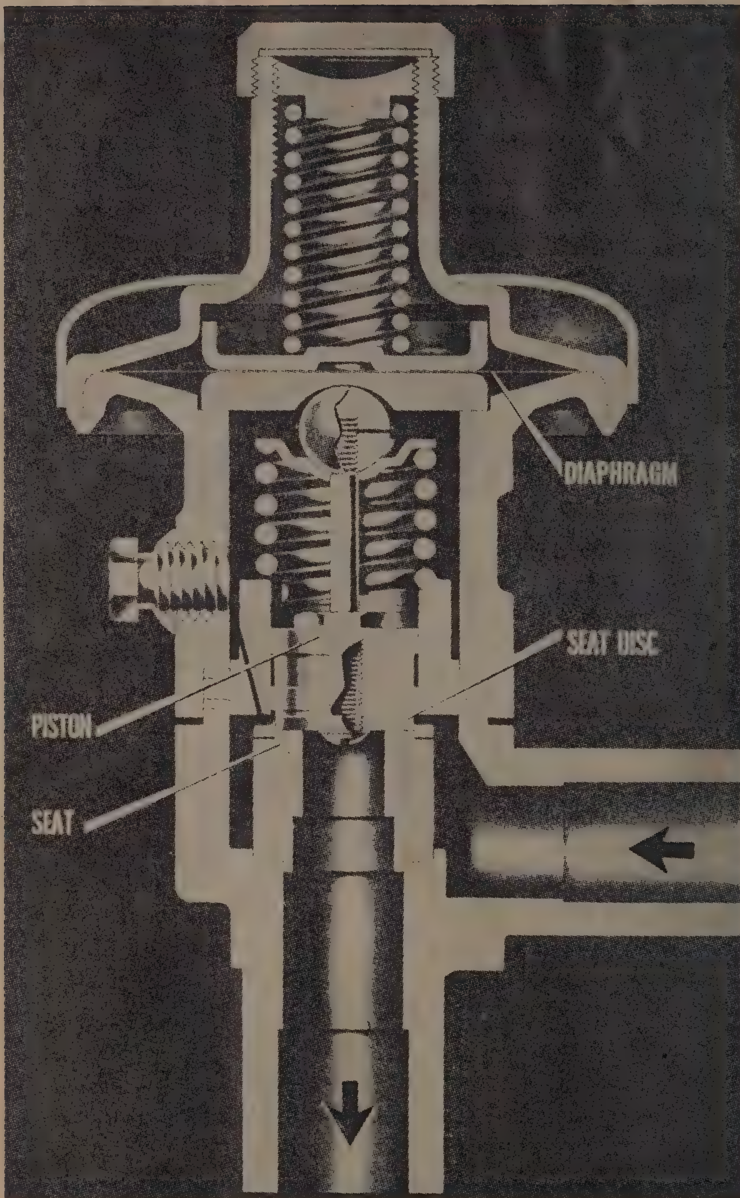


Figure 8–2.—Suction pressure regulating valve.

diaphragm balance. This diaphragm balance permits positioning of the valve which controls the refrigerant flow.

Compressor

Freon-12 compressors furnished for naval vessels are of the vertical, "V" or "W" enclosed, single-acting, reciprocating type. A cross-sectional assembly view of a typical compressor is shown in figure 8-3.

The compressor shown is equipped with double trunk pistons and integral suction valves. There is another common type that has single trunk pistons and suction valves located separately between the cylinder head and block. Both types of valves permit the entrance of refrigerant suction vapor directly to the cylinder block. The compressor is air-cooled.

COMPRESSOR VALVES.—Compressor suction and discharge valves are generally of the diaphragm type (fig. 8-3) or of the ring plate type. Special steel, surface finish, and temper are necessary for the thin diaphragms and ring plates. In the diaphragm type the inherent spring of the thin disk is sufficient to provide quick closing of the valves. The ring plate type has auxiliary springs to provide the necessary pressure between the valve ring and the sealing surfaces on the piston top or discharge valve plate.

COMPRESSOR LUBRICATION SYSTEM.—Freon-12 compressors may be provided with either forced feed lubrication or splash lubrication. (The compressor shown in figure 8-3 has splash lubrication.) In the latter case the oil level maintained in the compressor crankcase is relatively high and no oil pump is provided. Splash lubrication is perfectly satisfactory for small Freon-12 compressors. Most large Freon-12 compressors, however, are provided with oil pumps and full-pressure lubrication. A sight glass in the side of the compressor crankcase makes it possible to check the operating level of the lubricating oil in the compressor.

CRANKSHAFT SEAL.—A feature of compressors furnished for naval vessels is the provision of metallic crankshaft seals

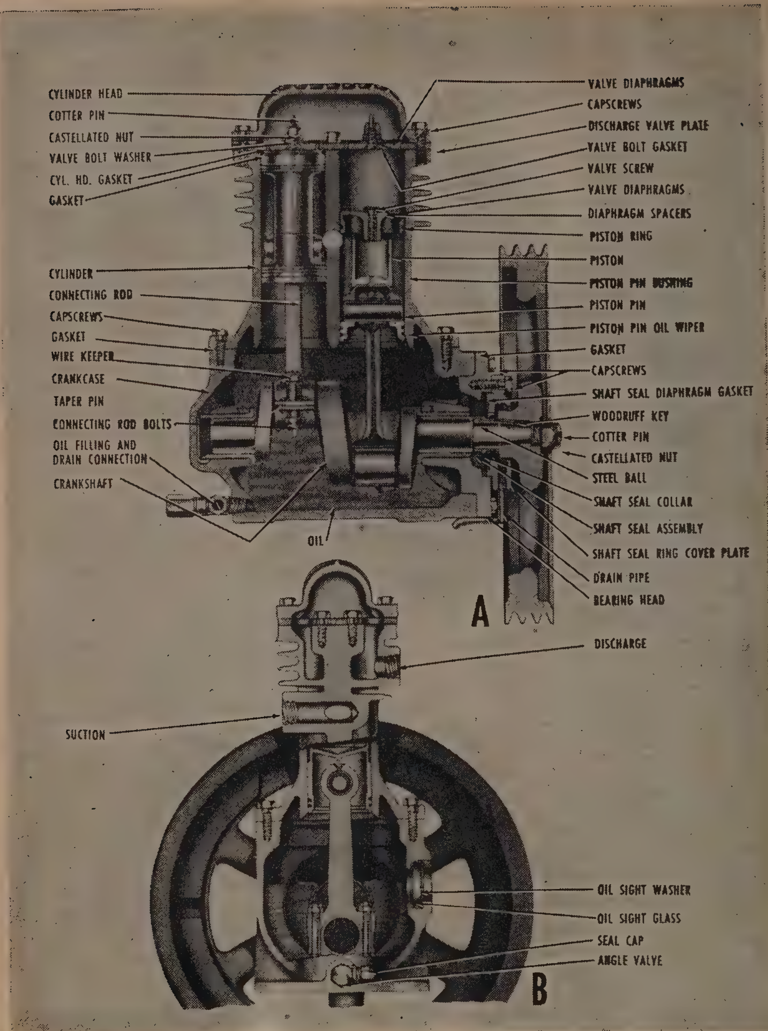


Figure 8–3.—Compressor, sectional view.

at the flywheel or pulley end of the crankshaft. These seals prevent leakage of the refrigerant and lubricating oil from the system at this point.

One type of shaft seal is a bellows assembly, in which a hardened steel seal collar fits against a shoulder; there is

a special rubber-like packing between the collar and the shoulder. The seal ring is held in position by a flexible metallic bellows and is pressed against the shaft seal collar by means of a spring.

The diaphragm type of shaft seal illustrated in figure 8–3 maintains a practically constant pressure on the seal surfaces with varying compressor crankcase suction pressures, because of the balancing effect provided by the arrangement of the thin metallic diaphragm with respect to the fulcrum ring.

V-Belt Drive.—Generally compressors are provided with a multiple V-belt drive; however, certain later designs utilize direct drive with connection between motor and compressor shaft through a coupling. The V-belts are built up of layers of rubber, cord, and fabric. Similar V-shaped grooves are provided on the motor pulley, which is generally of smaller diameter than the belt. A belt guard is furnished to enclose the V-belt and pulleys and prevent accidental injury to personnel and damage to equipment.

Low-Pressure Cut-Out Switch

In the compressor suction line between the suction line stop valve and the compressor, a connection leads to the low-pressure cut-out switch (often called the suction pressure control switch). This switch (see fig. 8–4) is located on the compressor base or on a panel adjacent to it. The refrigerant suction pressure acts on the metallic bellows of the power element of the switch, thereby producing movement of a lever mechanism which operates electrical contacts. These contacts are in a circuit connected to the compressor motor controller panel.

When all the solenoid valves have closed, thus halting the refrigerant flow, the suction pressure drops until it reaches the setting of the low-pressure cut-out (about 2 psi). When the suction pressure reaches this point, the switch opens, stopping the compressor. If the pressure should drop for any other reason, the cut-out switch stops the compressor at 2 psi. When one or more of the solenoid valves open, the

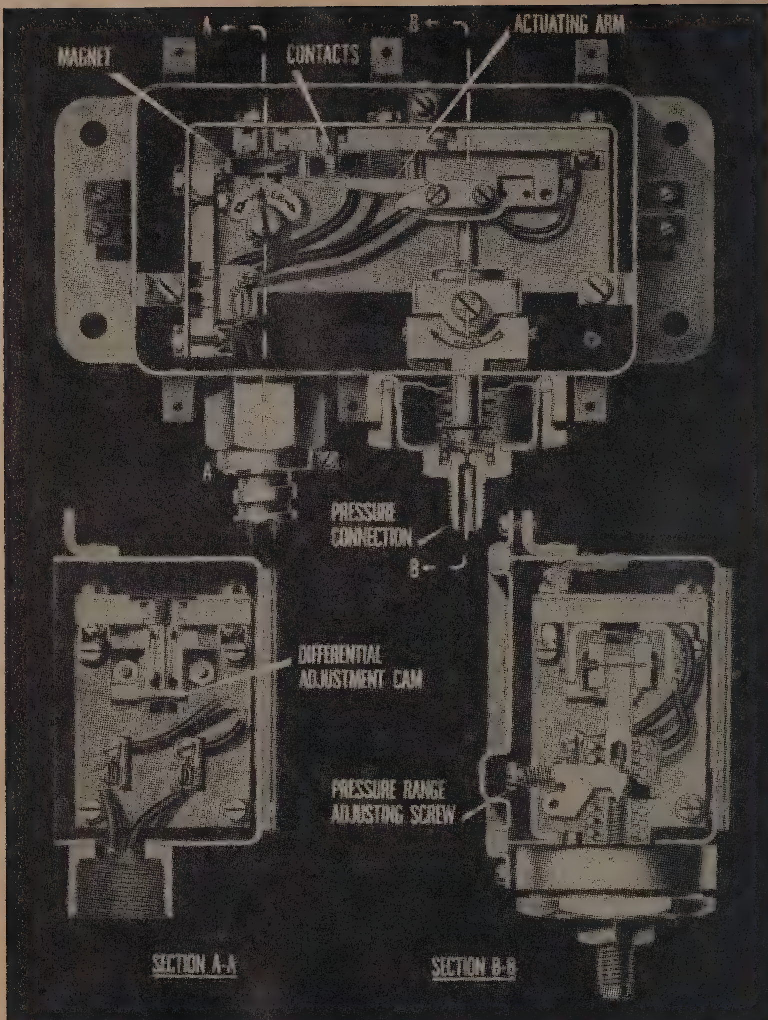


Figure 8–4.—Low- and high-pressure control switch.

suction pressure rises, causing the switch, which has a differential of about 18 psi, to close its contacts and start the compressor. That is, it stops the compressor when the low pressure drops to 2 psi, and snaps on at about 20 psi, restarting the compressor. The low-pressure cut-out provides auto-

matic control in the system. It halts the system when the desired degree of coolness in all spaces has been reached, thus making possible economical operation.

High-Pressure Cut-Out Switch

The high-pressure cut-out switch (see fig. 8–4) is also located on the compressor base or on a panel adjacent to it. The tubing leading to its bellows is connected to the high-pressure line. The wiring of this switch is connected to the pilot circuit of the compressor motor starter. This switch serves as a safety device to prevent dangerously high pressure from developing within the system. When the discharge pressure rises to the setting of this switch (usually 150 psi), the switch opens, stopping the compressor and shutting down the system. This switch has a differential of about 25 psi. When the high pressure falls to 125 psi, the switch closes, automatically starting the compressor again.

Relief Valve

The relief valve is of the conventional positive self-seating type, located on the discharge line from the compressor, or it may be designed into and located inside the compressor. It is furnished with interconnecting piping and serves to vent excessively high discharge pressure to the suction, or low-pressure, side of the compressor. The relief valve acts as an extra safety device; in the event that the high-pressure cut-out switch fails to stop the compressor, the relief valve comes into operation at 200 psi, preventing any further rise in pressure.

Condenser

The compressor discharge line terminates at the refrigerant condenser. Figure 8–5 shows a typical arrangement of a water-cooled condenser, the type used for all Freon–12 installations aboard ship. These condensers are of the multipass shell-and-tube type, with circulating water flowing through the tubes. The refrigerant vapor is admitted to the shell and condensed on the outer surfaces of the tubes. The

condenser is generally of the double tube sheet, straight tube type, with tube sheets silver-soldered to the shell. Bare tubes are normally provided. The tubes are expanded into grooved tube sheet holes to make an absolutely tight joint between the refrigerant in the shell and the circulating water.

Cooling Water Supply.—The circulating water for Freon–12 condensers may be supplied either by individual pumps taking suction from the sea or by a branch connection from the ship's fire and flushing main.

When individual circulating water pumps are installed,

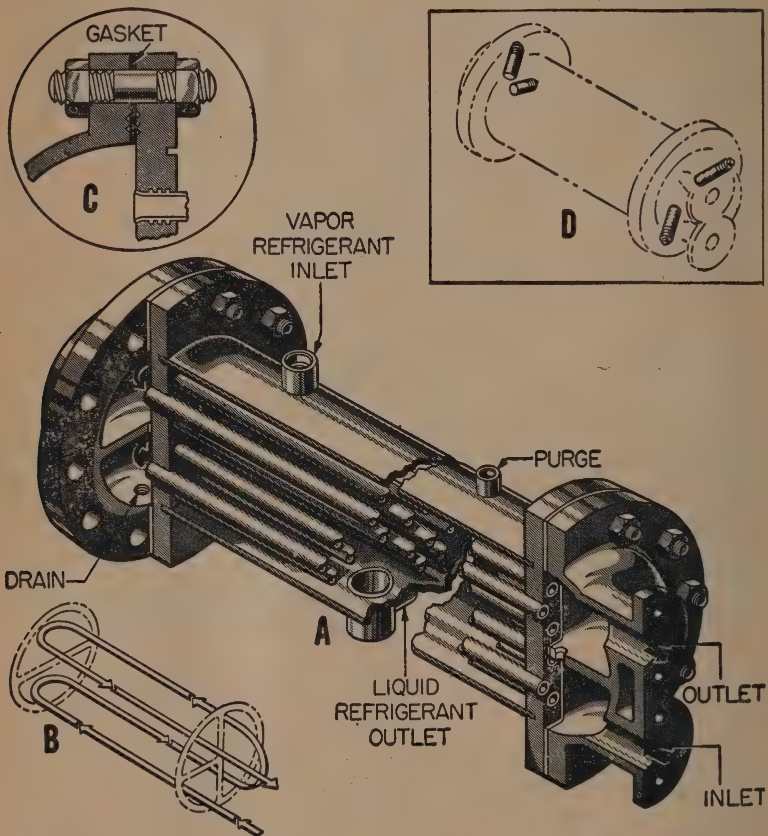


Figure 8–5.—Refrigeration condenser.

the pump motor controller is electrically interconnected with the compressor motor controller so that the circulating water pump starts and stops automatically with the compressor.

When the fire and flushing main connection is used, it is fitted with a pressure-reducing valve, and on older installations is provided with a relief valve to protect the condenser and equipment from excessive pressure. A condenser water-regulating valve is also installed to control the quantity of water flowing through the condenser.

Water Failure Switch.—Connections provided in the circulating water line from the pump and firemain lead to a water failure switch. This switch stops the compressor motor automatically in the event of failure of the circulating water supply. It is a pressure-actuated switch generally similar in construction to the low-pressure cut-out switch shown in figure 8–4. If the flow of condenser circulating water is interrupted, the pressure in the line decreases sufficiently to open the switch, thus opening the pilot circuit of the compressor motor controller and stopping the compressor.

Liquid Receiver

A liquid receiver is furnished to accumulate the reserve liquid refrigerant, to provide a storage for off-peak operation, and to permit "pumping down" the refrigerant so that the system may be secured or repaired. Stop valves are provided at each side of the receiver for confinement of the Freon–12 liquid refrigerant. (See fig. 8–6.)

A refrigerant drain valve is generally installed at a low point of the receiver shell or liquid piping for use in removing liquid refrigerant as necessary for making repairs to the system or for draining off excessive refrigerant from the system when it is inadvertently overcharged.

Dehydrator

A dehydrator (fig. 8–7) is inserted in the liquid line between the receiver and the evaporator. The piping connections include a valve bypass, so that the dehydrator can be

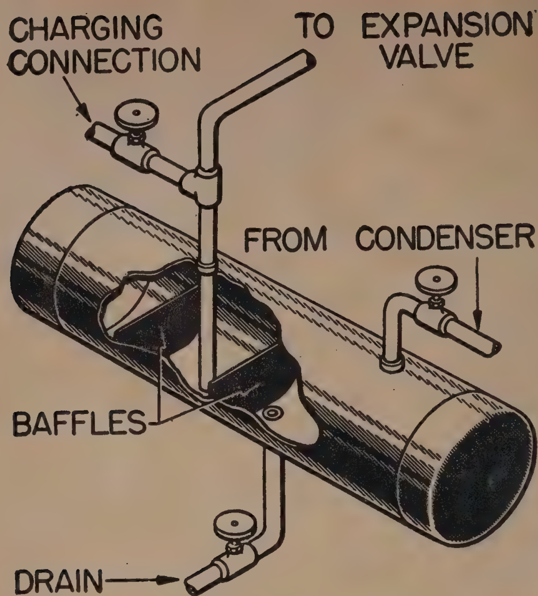


Figure 8–6.—Freon–12 receiver.

isolated when not in use. The function of the dehydrator is to remove moisture from the refrigerant in the system.

It is intended to be used only when charging the system with Freon–12, when adding refrigerant to compensate for loss through leaks, or when the presence of moisture in the system is suspected (as would be evidenced, for example, by a "freeze-up" at one of the expansion valves).

Sight Flow Indicator

A sight flow indicator is usually installed in the liquid line and is provided with bypass piping and valves to permit isolation of the indicator for repair or replacement. The indicator is a special fitting provided with a gasketed glass port on each side; it is furnished with seal caps for protection when not in use. Although a single port indicator may be used, the double port unit permits the use of a flashlight

background, where space is available, for a clearer view. The sight flow indicator allows you to view the Freon–12 and determine its condition as it passes through the pipe. The presence of bubbles in the liquid stream indicates an improper supply of refrigerant with resultant loss of capacity of the equipment.

King Solenoid Valve

A "king" solenoid valve may be installed next to the liquid sight-flow indicator in the main liquid refrigerant line. The function of this valve is to stop the flow of liquid refrigerant from the receiver when the compressor unit stops for any reason other than suction pressure control. This prevents excessive flooding of the cooling coils, or low side, with re-

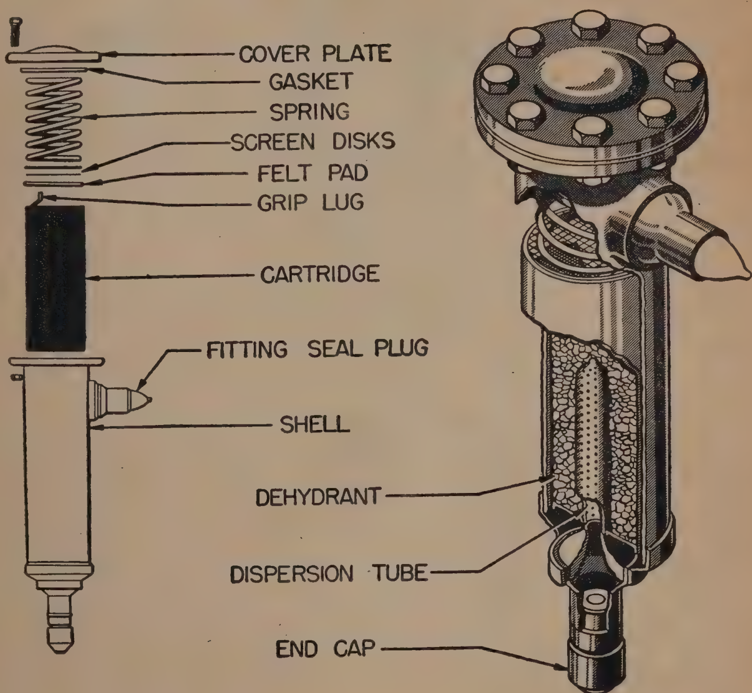


Figure 8–7.—Dehydrator.

frigerant. Such flooding might result in the return of liquid to the compressor unit upon starting. The "king" solenoid valve is electrically connected to the compressor motor starter control circuit.

Solenoid Valves

The solenoid valve (fig. 8–8) is located in the liquid refrigerant line ahead of each thermostatic expansion valve. When the current is on, the magnetic coil of the valve is energized; this causes the plunger to lift the valve from its seat, permitting the refrigerant to flow. When any of the other control devices break the electrical circuit, the magnetic coil releases the plunger, instantly closing the valve and completely stopping the flow of refrigerant.

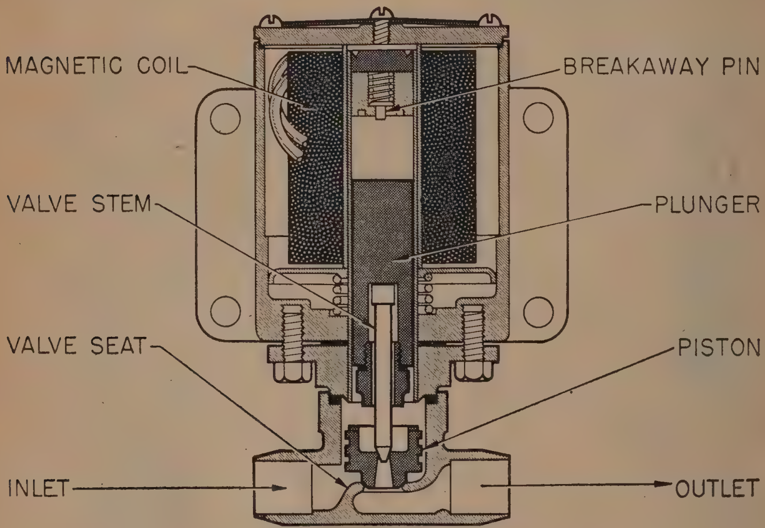


Figure 8–8.—Solenoid valve.

The function of the solenoid valve is to stop the flow of liquid refrigerant to the evaporator when the space being cooled has reached the desired temperature, and to open to permit flow when cooling is required. The solenoid valve is electrically actuated by a thermostatic switch which is responsive to temperature changes in the space being cooled.

Thermostat

The thermostat is an electrical switching device wired into the solenoid circuit for automatic control of refrigeration. It is controlled by temperature changes at a remote point by means of a long flexible tubing with an end bulb that may be placed at any desired location. The thermostat mechanism contains a flexible metal bellows, one side of which communicates with the remote bulb tubing filled with a volatile liquid similar to Freon–12. Remote bulbs for air contact operation are finned; bulbs for surface contact operation are bare of fins so that they may be clamped firmly against a pipe or other surface (see fig. 8–9).

As the temperature at the remote location drops to a desired point as a result of the refrigeration action, the corresponding pressure of the liquid within the tubing moves the bellows to its set operating position. In this position the bellows cause a spring-and-magnet-controlled contact to open, breaking the electric circuit and closing the solenoid valve. The snap action is rapid, thus preventing excessive arcing and ensuring long life of the contact points. Refrigeration, therefore, stops in the section controlled by this solenoid valve.

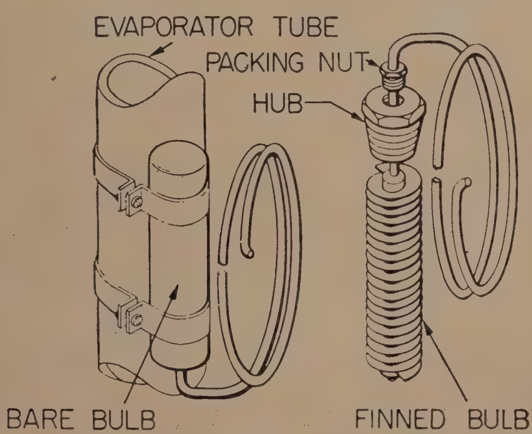


Figure 8–9.—Thermo-bulbs.

When the temperature at the same remote location rises above the desired point, the reverse action takes place. The switch snaps on, closing the electric circuit, thus opening the solenoid valve and starting refrigeration again. By this means, the desired temperature is maintained economically. When all solenoid valves are closed, the compressor is stopped by the low-pressure cut-out switch.

Thermostatic Expansion Valve

The function of the thermostatic expansion valve is to control the quantity of refrigerant that is admitted to the cooling coil and to reduce the pressure of the refrigerant from that existing in the condenser to that maintained in the coil. This valve is designed to feed into the coil enough refrigerant liquid to keep it working at its maximum effectiveness, in accordance with heat load variation, and to prevent the flooding back of liquid refrigerant to the compressor.

The design and construction of thermostatic expansion valves vary greatly. Figure 8–10 shows a cross-sectional assembly view of a type which is in general use aboard naval vessels. The valve shown illustrates the basic principles upon which all these valves operate. The control bulb of the valve, which is charged with Freon–12, is clamped to the suction line near the cooling coil outlet. The temperature changes in the suction line are reflected in corresponding pressure changes within the control bulb. These changes in pressure are transmitted through the control tubing to the diaphragm power element of the valve, which, in turn, transmits motion to the valve stem and needle. Good thermal contact between the bulb and the bare suction pipe is essential.

The liquid refrigerant is evaporated during its passage through the coil, and upon leaving the outlet end, the cold vapor cools the Freon–12 in the control bulb and decreases the upper diaphragm pressure, tending to close the valve.

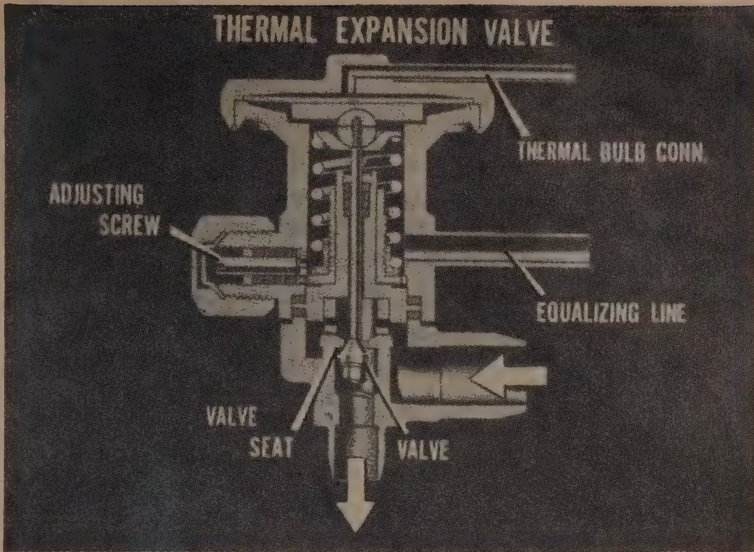


Figure 8–10.—Thermostatic expansion valve.

This reduction in valve opening reduces the quantity of refrigerant fed to the cooling coil and permits evaporation of all the liquid before the refrigerant reaches the outlet end where the control bulb is located. The refrigerant vapor becomes superheated during its passage through the remainder of the coil, beyond the point where all liquid is evaporated.

The amount of superheat depends on the valve spring pressure exerted on the diaphragm. For a given spring setting the valve maintains a relatively constant degree of superheat at the coil outlet, ensuring that all the Freon–12 liquid is evaporated before it leaves the coil to return to the compressor.

A bypass line equipped with a MANUALLY OPERATED EXPANSION VALVE is installed around the thermostatic expansion control valve and strainer to permit repair or cleaning of the main valve or strainer. The construction of the hand expansion valve is similar to that of the Freon line stop valve.

The refrigeration piping system consists of copper tubing and forged brass or wrought copper fittings, silver-soldered or brazed. Copper pipe assures freedom from corrosion by Freon–12 even in the presence of moisture. Copper does not contribute foreign matter to plug strainers, and the relative smoothness of the internal surface of copper pipe minimizes internal friction.

When the piping system is installed, it is arranged to permit various set-ups for the operation of the refrigeration plant. Sections or units of the entire system can be placed

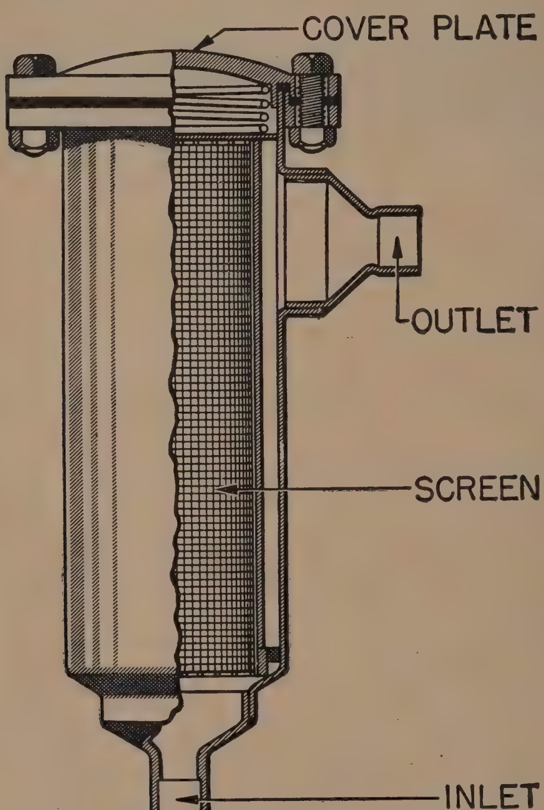


Figure 8–11.—Liquid strainer.

into operation with a complete unit of the system as a stand-by or spare. Sections of piping or equipment can be isolated for cleaning and repair of equipment.

Liquid Strainer.—The purpose of the liquid strainer is to remove foreign particles carried by the Freon–12 liquid before it passes through the compressor or the solenoid and expansion valves. In the process of installing a refrigeration system, a certain amount of foreign matter is left in the lines. Since the refrigerant piping system forms a closed circuit, particles of foreign matter will remain in the system unless trapped in a strainer or filter and removed by cleaning these units. Such foreign matter circulating through the system may score the compressor or system valve seats, clog expansion valve orifices, or cause the automatic valve mechanisms to stick.

Strainers consist of fine mesh metal screen arranged in a manner similar to that indicated in figure 8–11.

Packless Valves.—A number of packless stop valves (2-way and angle types) are inserted in the refrigerating circuit at various places. A 2-way diaphragm type valve is illustrated in figure 8–12. It contains a diaphragm that seals off the fluid flow chamber from the outside handle stem space. The lower stem is separate and is kept in contact with the upper stem, or handle part, by a spring; the sealing diaphragm is located between the two parts.

Gages and Thermometers.—The refrigeration system also includes the necessary pressure gages and thermometers for observing the pressures and temperatures at various places in the circuit.

Figure 8–13 illustrates the dial of a Freon–12 gage. The pressure and vacuum are shown on the inside scale, and the corresponding temperature on the outside scale. The wide pointer is a nonworking, or stationary, pointer that may be set manually to indicate the maximum working pressure. The gage for the suction, or low-pressure, side has a maximum reading of 150 psi. The gage for the discharge, or high-pressure, side (and the separate testing gage) has a

maximum reading of 300 psi. Both gages read down to 30 inches of vacuum.

NOTE: The temperature scale on the Freon–12 gage indicates only those temperatures of Freon–12 which correspond to the pressures measured. The gage cannot measure temperatures directly.

Liquid Control Manifold

A liquid control manifold may be used for certain applications to combine in one compact assembly the flanged line connections, shut-off valves, hand expansion valve, strainer, solenoid valve, and thermostatic expansion valve. This assembly eliminates a considerable quantity of piping and fitted joints, thereby minimizing the possibility of refrigerant leakage.

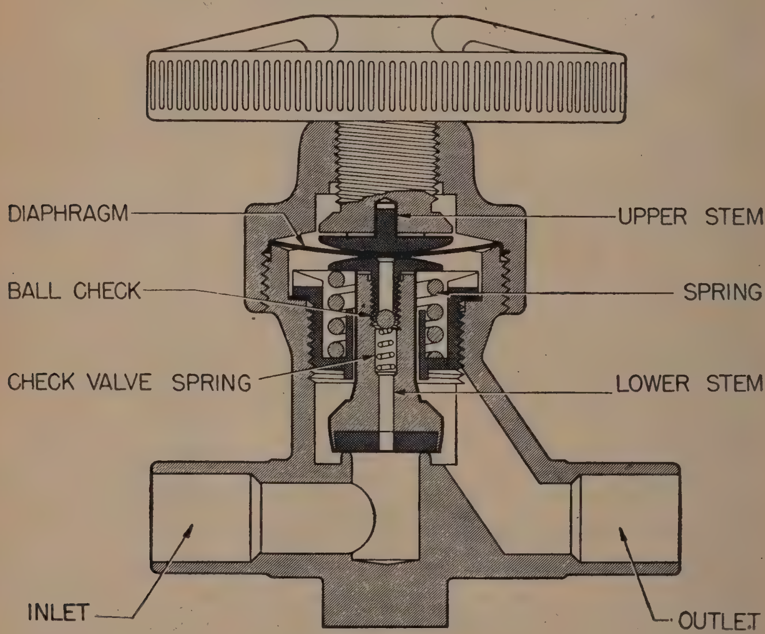


Figure 8–12.—Packless valve.

Operating Cycle

When the compressor is started, the spaces in which the cooling coils are located will be relatively warm and the solenoid valve control switches should be closed to hold the solenoid valves open. With the solenoid valves open, Freon flows from the liquid receiver to the thermostatic expansion valves which automatically admit the proper quantity of refrigerant to the cooling coils. As the compressor continues to operate, the temperature of the spaces in which the cooling coils are located gradually decreases and there is a corresponding gradual decrease in the compressor suction pressure. When the temperature of the refrigerated spaces has been decreased to the desired point, the solenoid valve control switches open, stopping the flow of refrigerant to the cooling coils. The compressor continues to operate for a short time, reducing the suction pressure until the low-pressure switch operates and stops the compressor motor. With the solenoid valves closed, refrigeration is cut off and the temperature of the refrigerated spaces gradually increases as a result of heat leakage, etc. When the temperature rises sufficiently to operate one or more of the solenoid valve control switches, refrigerant is again admitted to the cor-

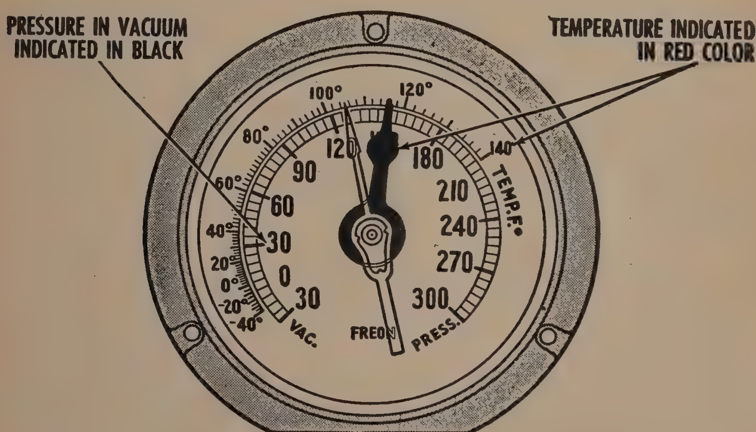


Figure 8–13.—Freon–12 gage.

responding cooling coils, and the compressor suction rapidly increases to the cut-in point of the low-pressure control switch; the switch closes, starting the compressor motor, and the operating cycle is repeated.

TYPICAL FREON–12 REFRIGERATION PLANT

The refrigeration system illustrated in figure 8–1 is a COMPLETE SYSTEM. In a typical refrigeration PLANT, however, there are at least two independent condensing units (including compressors, condensers, receivers, and supplemental equipment) connected to the refrigerant piping and cooling coils. The design capacity of each condensing unit is sufficient to carry the normal refrigerating load even when the vessel is operating in the tropics. This double machine arrangement is employed because cold storage refrigeration is regarded as a vital service and because this arrangement provides a spare unit for use in the event of derangement of the unit in operation. Aboard large naval vessels three or more complete and independent units of equal capacity are installed.

Piping is essentially the same as that previously described; provision for cross-connections for the condensing unit assembly is provided to permit operation of the spare refrigerating machine on the load. The refrigerant piping is arranged to permit independent operation of each compressor unit on a separate portion of the refrigerated load. This arrangement provides additional capacity for initial heat removal of refrigerators for loading and for emergency service.

OPERATING THE REFRIGERATION PLANT

The principal points you need to consider in operating the refrigeration plant are the starting and the stopping of the compressor, automatic operation of the compressor, the use of two or more compressors, and the maintenance of proper quantities of circulating water in the condenser.

Starting the Compressor

It is very important that the prescribed procedures for starting a compressor be carefully followed. Bent crankshafts, distorted valves, and blown gaskets are likely to result if proper precautions are not taken. Specific procedures differ somewhat for various installations, but some general rules can be given.

To start a compressor AFTER A SHORT SHUTDOWN, you should follow this procedure:

1. Check the oil level of the compressor. The oil level should be about the center of the oil sight glass. NEVER start the compressor when the crankcase is full of oil!
2. Check to see that the compressor suction valve and the compressor discharge valve are closed.
3. Open the supply and discharge valves in the cooling water circulating line for the condenser.
4. Open the compressor discharge valve.
5. Open the main liquid valve after the receiver.
6. Turn the compressor several times by hand to check for freeness of operation.
7. With the selector switch in the MANUAL position, start the compressor in short intermittent spurts until you are certain that the compressor is operating properly.
8. Crack the compressor suction valve slowly, with the compressor running, to limit the quantity of suction gas handled by the compressor. Observe the suction gage and gradually open the compressor suction valve at a rate that will prevent rapid fluctuations in suction pressure and at the same time avoid a rapid drop of pressure in the compressor crankcase.
9. Vent air, if present, from the water side of the condenser.

In starting the compressor AFTER A PROLONGED SHUTDOWN PERIOD, additional precautions must be taken. During a shut-down period the refrigerant pressure in the compressor crankcase will build up above its normal operating range;

therefore, in addition to turning the compressor several revolutions by hand to rid the cylinders of any possible oil accumulation, care must be exercised to avoid rapid pumping down of the crankcase pressure. Rapid reduction in crankcase pressure will cause violent boiling and foaming of the lubricating oil as the Freon–12 absorbed by the oil is released. If the oil is pulled from the crankcase, every precaution should be taken to avoid running the compressor without lubricant. Oil may be added temporarily and later removed if there is evidence of an excess in the crankcase. If 2-speed or adjustable-speed compressor motors are provided, the motor should be operated at reduced speed. A few starts with this precaution should suffice and the compressor may then be run continuously, provided, however, precautions against overloading the compressor motor are observed. The unit should be carefully observed for the first few hours of operation, and the motor should be stopped if overheating occurs. After the motor temperature has been reduced, the plant can be put back into operation.

Stopping the Compressor

To stop the compressor FOR A SHORT PERIOD, close the compressor suction valve slowly to prevent too rapid a reduction in crankcase pressure. Run the compressor until it stops automatically on the low-pressure control switch; then push in the STOP button on the motor control panel. Next, close the compressor discharge shut-off valve and shut off the water supply to the condensers. Close the main liquid valve after the receiver.

Shutting down a compressor FOR A LONG PERIOD is sometimes called PUMPING DOWN. That is, most of the liquid must be pumped out of the cooling coils of the evaporator and returned to the receiver. Only enough refrigerant gas is retained within the system to permit a positive pressure of approximately 2 psi (gage) throughout the circuit, except within the compressor discharge line, condenser, and receiver to the main liquid line shut-off valve.

Here is the prescribed procedure for pumping down:

1. Close the main liquid line shut-off valve and the dehydrator bypass valve, and open the dehydrator and strainer shut-off valves and the cooling coil solenoid valves.
2. Allow the compressor to operate on manual control until the suction pressure reaches approximately ½ to 2 psi; then stop the compressor.
3. Repeat this operation in periodic cycles until the liquid refrigerant in the circuit has evaporated and the suction pressure remains relatively constant at ½ to 5 psi. (The evaporation of liquid refrigerant can be traced on the liquid line back to the main liquid shut-off valve by the formation of frost and subsequent melting as the liquid refrigerant is evaporated and superheated.)
4. Open the power-supply switch to the compressor motor and the solenoid switches, and close the compressor suction and discharge shut-off valves.
5. Shut off the water supply to the condenser and then drain the condenser.

Automatic Operation of the Compressor

When satisfactory operation is established, the "automatic-manual" selector switch should be set in the automatic position which electrically connects the suction pressure control to start and stop the compressor automatically on load conditions.

Alternating and Parallel Operation of Compressors

It is not good practice to permit a Freon–12 compressor to remain idle for any extended period of time. Therefore, each of the compressors installed for a single refrigeration plant should be operated at least once a week. In addition, the total time that each of the compressors is operated should be kept approximately the same during the service life of the equipment. This is called ALTERNATING OPERATION.

PARALLEL OPERATION of two compressors on a common cool-

ing coil circuit should never be permitted unless an emergency requires such operation. Parallel operation could permit transfer of lubricating oil from one compressor to another, with the possibility of serious damage to all compressors involved, through lack of lubrication or excess oil pumping.

Condenser Circulating Water Quantity

As a general rule the quantity of circulating water flowing through the condenser should not exceed 6 gpm per ton of refrigeration. Larger quantities of circulating water produce correspondingly higher water velocities through the tubes, with attendant erosion of the tube and tube sheet surfaces. Suitable precautions should be taken to regulate the amount of circulating water flowing through the condenser.

CARE AND MAINTENANCE

A regular routine of checking the refrigeration system while it is in operation should be maintained to ensure proper care and operation. Make a complete check EVERY TWO HOURS of all temperatures and pressures throughout the system and of the oil level in the compressor crankcase. The necessity for taking any corrective measures can thus be determined before abnormal conditions can become acute.

We will now consider a few of the routine procedures for keeping the refrigeration system in good operating condition. Specific steps for detecting and correcting faulty operation of the system will be found in chapter 59 of BuShips *Manual*, in the manufacturers' instruction books, and in miscellaneous books on refrigeration systems.

Checking Compressor Oil Level

The oil level in the crankcase of the compressor should be from ½ to ¾ up in the sight glass. The primary difficulty in checking the oil level arises from the fact that Freon–12 mixes readily with oil. Therefore, the lubricating

oil will absorb appreciable quantities of Freon–12, and the Freon–12 will absorb appreciable quantities of oil. No chemical reaction takes place, but the mixing of the two may cause the oil level to appear high in the sight glass when actually the amount of oil is below normal.

This mixing of oil and Freon–12 has a definite pressure-temperature relationship. The absorption increases with elevation in pressure, lowering of temperature, and length of compressor shutdown. Therefore, a check of the oil level immediately after a prolonged shutdown is worthless as far as determining the actual working oil level is concerned. The ideal time for checking the oil level is after a prolonged period of operation, because then there will be the least amount of Freon–12 mixed with the oil. During the operation period, the refrigerant is pumped out of the oil.

Adding Oil

There are two common methods of adding oil to a compressor. In one type of installation a small oil-charging pump is furnished for adding oil to the compressor crankcase. In another type, oil is placed in the compressor by means of a clean well-dried funnel. In either case, one must be careful to prevent air or foreign matter from getting into the compressor.

For lubrication of Freon–12 compressors, Navy contract oil, symbol 2135, should be used. It can be obtained in one-quart cans, sealed to prevent the oil from absorbing moisture through contact with the atmosphere. If a can of lubricating oil is only partly used in charging a compressor, it is good practice to use the remaining oil for some other purpose not requiring the use of dehydrated oil. This practice will minimize the danger of charging the system with oil which is not perfectly dry.

Removing Lubricating Oil

To remove oil from the compressor crankcase, reduce the pressure in the crankcase to about 1 psi by gradually closing

the suction line stop valve. Then close the suction line valve, stop the compressor, close the discharge line valve, loosen the lubricating oil drain plug near the bottom of the compressor crankcase, and allow the required amount of oil to drain out. Since the compressor crankcase is under a slight pressure, do not fully remove the drain plug from the compressor, but allow the oil to seep out around the threads of the loosened plug. When the desired amount of oil has been removed, tighten the drain plug, open the suction and discharge line valves, and start the compressor. (If an oil drain valve is provided in lieu of a plug, the required amount of oil may be drained without the necessity of pumping down the compressor.)

Care of V-Belts

Excessive looseness will cause slippage, rapid wear, and deterioration of V-belts. A belt that is too tight will result in excessive wear of both the belt and main bearing of the compressor; in extreme cases it may cause a bad seal-leak. When properly tightened a belt can be depressed ½ to ¾ in., by the pressure of one finger, at a point midway between the flywheel and motor pulleys.

When replacement of one belt of a multiple V-belt drive is necessary, a complete new set of matched belts should be installed. It is better practice to run the unit temporarily with a defective belt removed than to attempt to operate a new belt in conjunction with two or more seasoned belts.

V-belts, motor pulley, and compressor flywheel should be kept dry and free of oil. Belt dressing should never be used.

Care of the Condenser

An inspection should be made at least monthly of the cleanliness of the water side of the condensers. Service conditions will indicate the routine to be followed in cleaning the condensers. The same procedure should be followed in checking on protector zincs in the condenser headers.

In order to avoid serious loss of refrigerant or the entrance

of circulating water through leaky condenser tubes, the water side of the condensers should be tested for leakage periodically (at least once every 2 weeks). The test should always be conducted on a condenser which has not been in use for at least 12 hours (after this amount of time there is usually a small air pocket at the top of the water boxes). To test, slowly open the water box vent valves, one at a time, and insert the exploring tube of a Freon–12 leak detector. If this test shows the presence of Freon gas, the exact location of the leak or leaks must be ascertained and necessary repairs made.

Air which may accidentally enter the refrigerant system will be drawn through the piping and discharged into the condenser with the Freon gas. The air accumulated in the condenser is lighter than the refrigerant gas and will rise to the top of the condenser when the plant is shut down. A purge valve is installed at the top of the condenser, or at a high point in the compressor discharge line, for purging accumulated air from the refrigerant system when necessary. The most satisfactory time to check the Freon system for presence of air, or noncondensable gases, is immediately before the compressor starts after a temporary or prolonged shutdown period. Care should be taken to avoid unnecessary waste of the refrigerant gas.

Checking and Adjusting the Thermostatic Expansion Valve

When the thermostatic expansion valve is working properly, the temperature of the pipe on the outlet side of the valve is 4° to 15° F. lower than the temperature of the pipe on the inlet side. The adjustment of the thermostatic expansion valve should not be attempted without reference to the manufacturer's instruction book. A thorough understanding of the valve's operation is also necessary, since what appears to be a defective valve may be due to other conditions, such as shortage of refrigerant, clogged strainer or orifice, or the freezing of moisture or vapor in the liquid refrigerant ahead of the valve.

Once a valve is properly adjusted, further adjustment should not be necessary.

Maintenance of Refrigerated Rooms

To maintain a satisfactory performance of the refrigeration plant, observe the following precautions:

1. The number of entries and length of time of each entry into the refrigerated spaces must be limited and properly controlled.
2. The refrigerator doors must be shut tightly and they must be kept in good condition.
3. The goods must be stored so as to interfere as little as possible with free circulation of the air. Care should be taken not to stow boxed food too compactly, because lack of air circulation around the boxes may cause spoilage.
4. The sheathing of the refrigerated spaces should be inspected and the air tested periodically to ascertain that watertightness is being maintained at all seams and that the sheathing has not been punctured.

Defrosting Cooling Coils

The cooling coils should be defrosted as often as necessary to maintain the effectiveness of the cooling surface. Excessive accumulations of frost on the coils will result in reduced cooling capacity. It is good practice to defrost cooling coils before the average frost thickness reaches $3/16$ inch in the average cold storage refrigerating plant installation. This rule is only approximate, however; in some cases the frost layer may become appreciably thicker without seriously interfering with plant operation, while in other cases, particularly when operating in the tropics, more frequent defrosting may be necessary, to maintain satisfactory operation of the plant.

Many current Freon–12 plant installations are provided with "hot gas" defrosting lines to facilitate defrosting of the meat room evaporator. These lines permit defrosting of the coils without the necessity of elevating the compartment temperature above 32° F.

Keeping Moisture Out of the Freon–12 System

It is extremely important that water or moisture be kept out of the Freon–12 system. Water is only very slightly soluble in Freon–12; therefore, any appreciable quantity of moisture which is accidentally introduced into the system will cause improper functioning of the automatic controls. Ice will form at the expansion valves, causing the valve mechanism to stick in the open or closed position and clogging the expansion orifices. Moisture also has the tendency to cause the thin metallic diaphragms and bellows used in the automatic control equipment to become brittle under cyclic stress.

Internal surfaces of the system, in general, are subject to corrosion and deterioration if appreciable quantities of moisture are present, since the Freon–12 thoroughly cleans the metal surfaces and leaves the bare, uncoated surface exposed. Water in the system mixes with the lubricating oil to form a sludge which seriously interferes with proper compressor lubrication and proper operation of the various automatic control units.

Testing for Leaks in the Freon–12 System

A shortage of refrigerant in the system nearly always indicates the presence of leaks; when this occurs the entire system should be tested for leaks.

Freon–12 leaks are detected by a specially designed torch known as the HALIDE TORCH. Several types of halide torches, most of which use acetylene gas or alcohol as a fuel, are available. A halide torch is so sensitive, however, that it cannot be used in testing for large leaks where the atmosphere in the space is permeated with the refrigerant vapor.

Testing by means of soapsuds is also used, especially where there is a high concentration of Freon–12 gas in the atmosphere.

Oil should never be used in testing for leaks, as it will absorb Freon–12 gas. Also, oil will interfere with the use of a halide torch for testing.

Always follow a definite plan in testing for leaks, so that no joints are missed. Be sure that you find EVERY leak; even a very small leak is not to be considered negligible. Upon locating one leak, retest the system for other possible leaks.

Charging the Freon–12 System

A refrigerating system should have a complete charge of refrigerant at all times; otherwise, the efficiency and capacity of the plant will be impaired.

The Freon–12 charge must be sufficient to maintain a liquid seal between the condensing and evaporating sides when all cooling coils are working simultaneously under a load such as would be encountered after refrigerators are loaded.

The system must never be recharged until all leaks are found and completely repaired. Immediately after or during the process of charging, the system should be carefully inspected for leaks.

In charging the Freon system one should follow the detailed instructions for the particular refrigeration plant being serviced.

Cleaning Strainers

The strainers should be inspected frequently during the early service life of the plant and after major repairs; they should be cleaned when necessary. Service experience will dictate the frequency with which it is necessary to clean the strainers. A schedule should be set up as soon as possible to provide for cleaning strainers at regular intervals.

QUIZ

1. What is the name of that portion of the refrigeration system from the orifice of the expansion valve, through the evaporator, up to and including the intake side of the compressor cylinders?
2. What refrigerant is used most extensively on naval vessels?
3. What is used as a secondary refrigerant to carry heat from stored food to the cooling coils?
4. What types of compressor suction and discharge valves are generally used in refrigeration systems?
5. What prevents leakage of the refrigerant and lubricating oil from the crankcase of the compressor?
6. With what type of drives are refrigeration compressors provided?
7. How does the low-pressure cut-out contribute to the economical operation of the system?
8. What important valve is located between the discharge and suction lines at the compressor?
9. Where is the reserve liquid refrigerant accumulated?
10. Where is the dehydrator located in the liquid line?
11. What functions to stop the flow of refrigerant from the receiver when the compressor unit stops for any reason other than suction pressure control?
12. What methods are used to join the various sections of copper tubing, piping, and fittings of the refrigeration system?
13. Why are cross-connections for the condensing unit assembly provided?
14. How often should each compressor installed for a single refrigeration plant be operated?
15. How often should a complete check be made of all temperatures throughout the system and the oil level in the compressor crankcase?
16. What is the proper oil level in the crankcase of the compressor?
17. What type oil is used in the crankcase of Freon–12 compressors?
18. When removing oil from the compressor, why should you not completely remove the drain plug?
19. What type of belt dressing should be used on compressor V-belts?

20. How often should an inspection for cleanliness of the water side of the condensor be made?

21. How often should the water side of the condensor be tested for leaks?

22. What should be used immediately as an irrigant for the eyes after contact with Freon–12?

23. As a general practice, the cooling coils should be defrosted before the frost reaches what thickness?

24. What is provided on many current Freon–12 plants to facilitate defrosting without elevating the compartment temperature above 32° F.?

25. What device has been specially designed for detecting the locations of Freon–12 leaks?

26. What instructions should be followed for charging the Freon–12 system?

CHAPTER 9

AIR CONDITIONING

Air conditioning is the science of establishing and maintaining the atmosphere of an enclosed space at a specified temperature, humidity, and purity. In the broadest sense of the term, air conditioning involves heating, cooling, humidifying, dehumidifying, circulating, and purifying the air. However, for the purpose of this course, the term refers to the mechanical cooling, dehumidifying, and circulating of the air.

PURPOSES OF AIR CONDITIONING

The chief purpose of air conditioning is to keep the ship's personnel comfortable, alert, and physically fit at battle stations. Within the enclosed quarters of a ship during general quarters, circulation of the air tends to become very poor and the heat and moisture given off by the human body and by equipment increase the temperature and the moisture content of the air. Research has shown that air temperatures and moisture content above certain limits, and lack of air circulation, are not conducive to the comfort and efficiency of the human body. Therefore, proper air conditioning of the ship is very important.

Air conditioning is also provided in ammunition spaces, to prevent deterioration of ammunition components; in gas storage spaces, to prevent excessive expansion of the gases or dangerous contamination; and in electrical equipment spaces, to prevent condensation of moisture on the equipment.

THEORY OF AIR CONDITIONING

Air and Water Vapor

Water vapor is always present in atmospheric air. This atmospheric moisture, called HUMIDITY, has a great influence on human comfort. The common expression, "It isn't the heat, it's the humidity," is an indication of the popular recognition of the discomfort-producing effects of moisture-laden air in hot weather. Extremely low moisture content also has undesirable effects on the human body. The measurement and control of the moisture content of the air is an important phase of air conditioning engineering.

In order to undertand this phase of air conditioning engineering, you should be familiar with the following terms.

SATURATED AIR.—The air holds varying amounts of water vapor, but for every temperature there is a definite limit to the amount of moisture that the air is capable of holding. When air at a given temperature attains this maximum amount of moisture, it is known as saturated air. It should, however, be pointed out that saturated air at different temperatures holds different amounts of vapor; the higher the temperature, the more moisture the air can hold.

DEW POINT.—The saturation point is usually called the dew point. If the temperature of saturated air falls below its dew point, some of the water vapor in the air must condense to water. The dew that appears on foliage in the early morning, when there is a drop in temperature, is such a condensation. The "sweating" of cold water pipes also is the result of water from the air condensing on the cold surface of the pipes.

ABSOLUTE AND SPECIFIC HUMIDITY.—The amount of water vapor in the air is expressed in terms of its weight. This weight is usually given in grains (7000 grains equal 1 pound). Absolute humidity is the weight in grains of water vapor per cubic foot of air. Specific humidity is the weight in grains of water vapor per pound of dry air. Specific humidity is the more generally used. (It should be understood that

the moisture indicated in these definitions refers only to moisture in the vapor state, and not in any way to the moisture that may be present in the liquid state, such as fog, rain, or dew.)

Relative Humidity.—Relative humidity is the ratio of the weight of water vapor in a sample of air to the weight of water vapor that same sample of air would contain if it were saturated. This ratio is usually stated as a percentage. For example, when air is fully saturated, its relative humidity is 100 percent. When air contains no moisture at all, its relative humidity is zero percent. If air is half-saturated, its relative humidity is 50 percent.

As far as comfort and discomfort resulting from humidity are concerned, it is the relative humidity and not the absolute or specific humidity that is the important factor. This can be easily understood from the discussion in the following paragraphs.

It should be understood that moisture always travels from regions of greater wetness to regions of lesser wetness, just as heat travels from regions of higher temperature to regions of lower temperature. If the air above a liquid is saturated, the two are in equilibrium and no moisture can travel from the liquid to the air; that is, the liquid cannot evaporate. If the air is only partially saturated, some moisture can travel to the air; that is, some evaporation can take place.

Suppose the specific humidity of the air is 120 grains per pound of dry air. This is the actual weight of the water vapor in the air. If the temperature of the air is 76° F., the relative humidity is then nearly 90 percent—that is, the air is nearly saturated. The body perspires but the perspiration does not evaporate quickly because the air already contains nearly all the moisture it can hold. The general feeling of discomfort is a warning that the environment under such conditions is not suitable for the best maintenance of health.

If the temperature for the above air is 86° F., the relative humidity would then be only 64 percent. That is, although the absolute amount of moisture in the air is the same, the relative amount is less, because at 86° F. the air can hold

more water vapor than it can at 76° F. The body is now able to evaporate its excess moisture and the general feeling is much more agreeable, even though the air temperature is 10 degrees hotter.

In both cases, the specific humidity is the same, but the ability of the air to evaporate liquid moisture is quite different at the two temperatures. This ability to evaporate moisture is indirectly indicated by the relative humidity. It is for this reason that in air conditioning extreme importance is placed upon the control of relative humidity.

Measurement of Air Temperatures

Three different temperatures are needed to understand and control the air-conditioning operations. These are the dry-bulb, wet-bulb, and dew point temperatures.

The DRY-BULB TEMPERATURE is the temperature of the air as measured by an ordinary thermometer. Such a thermometer in air-conditioning engineering is called a dry-bulb thermometer, because its bulb is dry, in contrast to the wet-bulb type next described.

The WET-BULB TEMPERATURE is best explained by a description of a wet-bulb thermometer. It is an ordinary thermometer with a loosely woven cloth sleeve or wick placed around its bulb and then wet with water. The cloth sleeve must be clean and free from oil and wet thoroughly with clean fresh water. The water in the cloth sleeve is caused to evaporate by a current of air at high velocity. This evaporation withdraws heat from the thermometer bulb, lowering the temperature a number of degrees. The difference between the dry-bulb and wet-bulb temperatures is called the wet-bulb depression. The wet-bulb temperature is the same as the dry-bulb when the air is saturated, which is a condition where evaporation cannot take place. The condition of saturation, however, is unusual, and a wet-bulb depression is normally to be expected.

In air conditioning work, the two thermometers, wet-bulb and dry-bulb, are usually mounted side by side on a frame, to which a handle or short chain is attached so that the ther-

mometers may be whirled in the air, thus providing the high-velocity air current for evaporation. Such a device is called a SLING PSYCHROMETER. The psychrometer must be whirled around rapidly, at least four times per second. When the wet-bulb thermometer is examined at intervals, its temperature reading will be found to be dropping; when no further drop is observed, that reading gives the correct wet-bulb temperature.

The DEW-POINT TEMPERATURE is the temperature at which the water vapor present in the air begins to condense—that is, the temperature existing at the point of SATURATION of the air.

There are definite relationships between these three temperatures:

1. When the air contains some moisture but is not saturated, the dew-point temperature is lower than the dry-bulb temperature, and the wet-bulb temperature lies between them.
2. As the amount of moisture in the air increases, the difference between the temperatures grows less.
3. When the air is saturated, all three temperatures are the same.

Psychrometric Chart

There is a relationship between dry-bulb, wet-bulb, and dew-point temperatures, and specific and relative humidity. Given any two, the others can be calculated. However, the relationship can be shown on a chart, called a psychrometric chart (see fig. 9–1). In air conditioning it is customary to use this chart, since this is far easier than calculating. To use the chart, take the point of intersection of the lines of the two known factors, and from this point follow the lines of the unknown factors to their numbered scales and read the measurement.

Air Motion

It is a well-known fact that when the air in a room is motionless, the room soon feels stuffy to its occupants, even

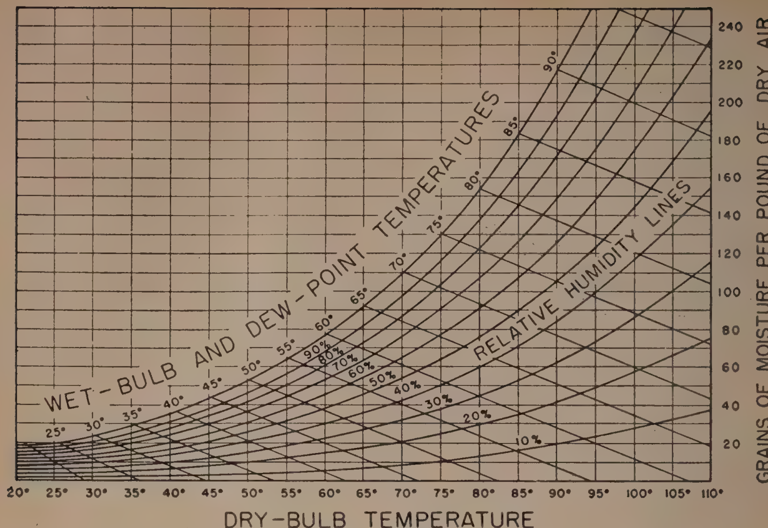


Figure 9–1.—Psychrometric chart.

though the air may be quite fresh. On the other hand, air that is kept stirred, even if it is somewhat stale, at least does not feel stuffy, and though perhaps too warm, is nevertheless bearable.

When the air in a room is stirred, three effects on the human body result, all adding up to a feeling of greater comfort. One is a purely sensory effect, another affects humidity, and the third affects temperature. The three are closely interrelated and depend upon the velocity of the air motion.

Sensory Effect of Air Motion.—Air in motion has a definite action on the sensory organs in the skin. When the air has a gentle motion, a velocity of 20 to 50 feet per minute (fpm), the tactile sensory nerves in the skin are stimulated, and a feeling of greater comfort is experienced than when the air is completely still.

Effect of Air Motion on Humidity.—The body is always evaporating moisture, even though the evaporation may be at such a slow rate that it is not perceptible as perspiration. If the air is still, this evaporated moisture stays close, form-

ing with the heat also given off, a damp, hot blanket around the body. Within such a blanket, air is less able to absorb the evaporation from the body; hence a feeling of discomfort ensues. But if the air is stirred, the convection currents thus formed carry away the moisture as rapidly as it is given off, and a normal rate of evaporation is maintained.

Effect of Air Motion on Temperature.—The body is always giving off heat to the air around it by conduction. If the air is still, the air close to the body gradually becomes heated, and this heat is not carried away. Thus, although the average temperature of the air in a room may remain nearly constant, the body itself is in air of higher temperature. If the air is in motion, however, the heat coming from the body cannot build up, but is carried away by convection.

Body Heat Balance

Ordinarily the body remains at a fairly constant temperature of 98.6° F., and it is very important that this temperature be maintained by the body. Since the body is continually receiving a heat gain from surrounding and interior processes, there must also be a continuous outgo of heat to keep a balance. This excess heat must be absorbed by the surrounding air. The body automatically regulates the amount of heat which it gives off as the temperature and humidity of the environment vary, but this ability to adjust to varying environmental conditions is limited. Furthermore, although the body may adjust to certain atmospheric conditions, it may do so with a distinct feeling of discomfort. The following discussion will help you to understand how atmospheric conditions affect the body's ability to maintain a heat balance.

The body gains heat (1) by radiation, (2) by convection, (3) by conduction, and (4) as a by-product of physiological processes that take place within the body.

The heat radiation gain comes from our surroundings, but since heat always travels from regions of higher temperature to regions of lower temperature, such surroundings must

have a temperature higher than 98.6° F. if the body is to receive heat from them. Indoor heat radiation is gained from heating devices, operating machinery, hot steam piping, etc. The greatest source of heat radiation is the sun.

The heat convection gain comes from currents of heated air only. Such currents of air may come from a galley stove.

The heat conduction gain comes from objects with which the body may, from time to time, be in contact.

Most of the body heat comes from within the body itself. Heat is being continuously produced inside the body by the oxidation of foodstuffs and by other chemical processes.

Body heat losses are of two kinds, sensible and latent. Sensible heat is given off by three methods: (1) radiation, (2) convection, and (3) conduction. Latent heat is given off by evaporation.

The body is usually at a higher temperature than that of its surroundings, and therefore radiates heat to walls, floors, ceilings, and other objects. This action is called heat radiation loss. The temperature of the air does not influence this radiation, except as it may alter the temperature of such surroundings.

The heat convection loss occurs when the heat is carried away from the body by convection currents, both by the air coming out of the lungs and by exterior air currents. These may exist in the air itself or be caused by a person's moving about.

The heat conduction loss is caused by bodily contact with colder objects or substances. Since the body is usually at a higher temperature than that of its surroundings, it gives up heat by conduction through physical contact with them.

The heat loss by evaporation is the loss of heat due to the cooling effect of vaporization of the body's moisture. Under normal air conditions, the body gets rid of much excess heat by this method. The heat inside the body is sensible heat; during evaporation, it becomes latent heat. The rate of evaporation, and hence of heat loss, depends upon the temperature, relative humidity, and motion of the air.

When the temperature and relative humidity are not too high, and when the body is not too active, the body gets rid of its excess heat by radiation, convection, and conduction. When engaged in work or exercise, the body develops much more internal heat, and perspiration begins. Perspiration rapidly evaporates if the relative humidity is low. If, however, the relative humidity of the air is high, the moisture cannot evaporate, or does so only at a slow rate. In such cases, the excess heat cannot be removed by evaporation, and discomfort follows.

The amount of heat given off by the body varies according to the body's activity. When seated at rest, the average adult male gives off about 380 Btu per hour. On a ship, a man gives off from 500 to 600 Btu per hour as an average over a 24-hour day.

Research has shown that the total amount of heat loss is divided as follows for light work on a ship: About 45 percent by radiation, 30 percent by convection and conduction, and 25 percent by evaporation. Research has shown further that for normal body comfort, it is important that the heat loss be in these proportions.

Thus, if a person loses the same total of heat in the proportions of 40 percent by radiation, 50 percent by convection and conduction, and 10 percent by evaporation, he feels uncomfortable, damp, and chilly. This represents a condition of high relative humidity and too much air motion, as from a direct draft or fan breeze. On the other hand, if the total heat loss is the same, but divided in the proportions of 30 percent by radiation, 25 percent by convection and conduction, and 45 percent by evaporation, he feels uncomfortable, hot, and parched. This represents a condition of low relative humidity and no air motion.

It is apparent that while the heat loss may be a desirable amount in total, it may be so given off as to produce distinct discomfort. It is essential that the air conditioning be so controlled as to enable these heat losses to occur in the best proportions to produce comfort.

Sensation of Comfort

From the foregoing discussion it is evident that the three factors—temperature, humidity, and air motion—are closely interrelated in their effects upon comfort and health. In fact, a given combination of temperature, humidity, and air motion will produce the same feeling of warmth or coolness as some other temperature with a compensating humidity, and air motion. It is the net effect of these factors, then, in which we are interested. The term given to this net effect is EFFECTIVE TEMPERATURE. This temperature cannot be measured by any instrument but may be found on a special psychrometric chart when the dry-bulb and wet-bulb temperatures and air velocity are known.

Though all the combinations of temperature, relative humidity, and air motion of a particular effective temperature may produce the same feeling of warmth or coolness, they are not all equally comfortable. It has been found that a relative humidity below 15 to 20 percent produces a parched condition of the mucous membranes of the mouth, nose, and lungs, and increases susceptibility to disease germs. A relative humidity above 70 percent causes an accumulation of moisture in clothing. For best health conditions, a relative humidity of from 40 to 50 percent for cold weather and from 50 to 60 percent for warm weather is desirable, and an over-all range of from 30 to 70 percent is acceptable.

There is also an optimum range of air velocity. This range is from about 15 to 20 fpm to about 100 fpm. In general, if an air current is definitely perceptible—that is, if it attracts attention—then it is too much for comfort and may be a hazard to health.

A chart known as a COMFORT CHART has been constructed to indicate the ranges of temperatures, relative humidities, and air velocities which produce a normal feeling of comfort for most persons. Such a chart is shown in figure 9–2. This chart is for air velocities of from 15 to 25 fpm. You will note that the range of acceptable conditions for winter is different from the range for summer.

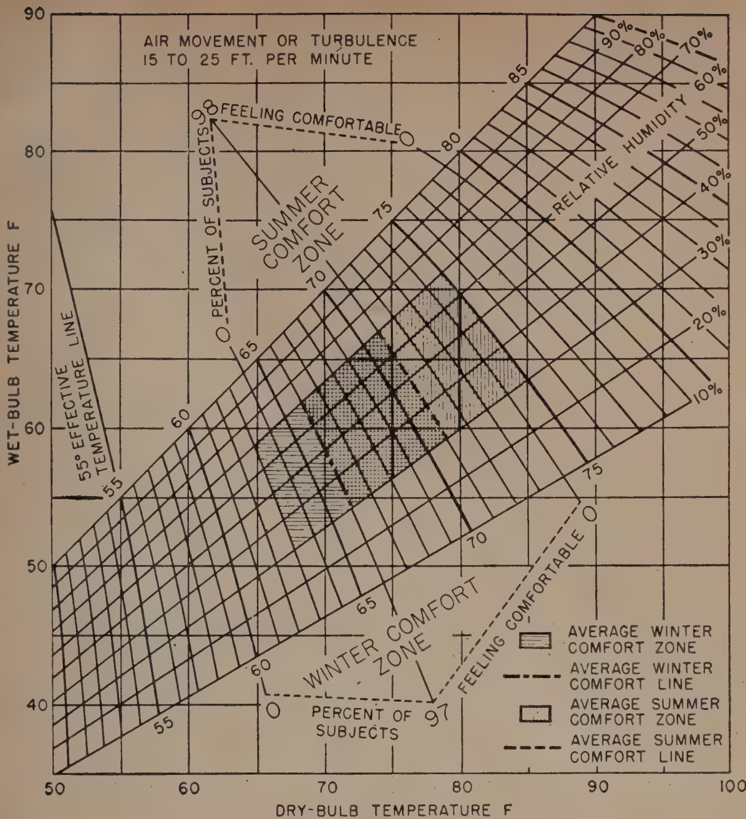


Figure 9–2.—Comfort chart.

AIR CONDITIONING PLANTS

The basic function of an air conditioning plant or system is to remove the heat from a compartment and discharge it overboard. (The removal of heat results not only in lowering the temperature but also in dehumidification.) In some types of plants the heat is picked up from the compartment by means of a chilled water system. This heat is transferred from the chilled water to the salt water, which is pumped overboard. This transfer of heat cannot be accomplished by the conventional heat exchanger; therefore, other

methods and equipment must be used. The mechanical refrigeration plants achieve this transfer of heat.

At the present time there are several types of air conditioning plants used by the Navy, the design and construction depending upon the characteristics of the refrigerant used. These plants are more or less in an experimental status to determine which type is best suited to naval use. Freon–12, steam jet, and lithium bromide are plants that have been installed on naval vessels.

Freon–12 Plant

The Freon–12 air conditioning plant is a mechanical compression system. The refrigerant cycle in this plant is the same as that in the ship's main refrigeration plant; and, in general, the machinery, equipment, and piping arrangements of the two plants are similar. The only major difference is in the construction of the evaporator or cooling coils.

In air conditioning installations the external equalizer is used with the thermostatic expansion valve in place of the internal equalizer. The internal equalizing port between the valve outlet and the spring chamber is eliminated. Instead, there is an opening through the wall of the valve directly into the spring chamber. The spring chamber is connected by means of copper tubing to the evaporator coil, beyond the point of greatest pressure drop. The external equalizer is used because in the air conditioning system there is a larger pressure drop between the two ends of the cooling coils than in the refrigeration system. This pressure drop is due to the use of smaller tubing which has restricted return bends.

The Freon–12 reciprocating compressors are built in different sizes. The size of the compressor varies in accordance with the capacity required. Compressors in an air conditioning system are similar to the refrigeration system compressors.

Operating suction pressures and evaporator temperatures used in the air conditioning systems are higher than those used in refrigeration systems. This change of suction pres-

sure causes a corresponding change in the rated capacity of the compressor. More refrigerated tons are developed at the higher suction pressure, or higher evaporator temperature.

Steam Jet Plant

The steam jet plant operates on the principle of cooling water by evaporation. It is classified as a thermocompression plant. Except for a few pumps, this type of cooler has no moving parts.

The major parts of this plant are: (1) the flash tank, (2) the booster ejector, (3) the condenser, and (4) the air ejector. (See fig. 9–3.)

Water from the chilled water system is continuously sprayed into the cold flash tank by nozzles in the spray pipes. The pump keeps the water in circulation throughout the chilled water system and returns it to the flash tank or evaporator.

Upon entering the flash tank, which is under a very high vacuum, a small part of the sprayed water flashes into vapor and by this action absorbs heat from the remaining water. It is necessary to flash only a very small part of the water to produce the desired cooling effect.

The flashed vapor is removed from the flash tank by the booster ejector and sent to the condenser. The booster ejector is supplied with steam and works on the same principle as an air ejector in maintaining a vacuum in the flash tank.

The condenser and the air ejectors work on the same principles as similar units found on a steam-driven ship. The vapor and steam from the booster ejector are condensed, and the condensate is returned to the ship's steam heating drain system. The air ejectors, which are of the conventional two-stage design, maintain a vacuum on the condenser.

The steam jet plant is designed for automatic operation after the necessary starting operations have been completed. During light loads the booster ejector will function in an on-off cycle, and the other component parts will operate con-

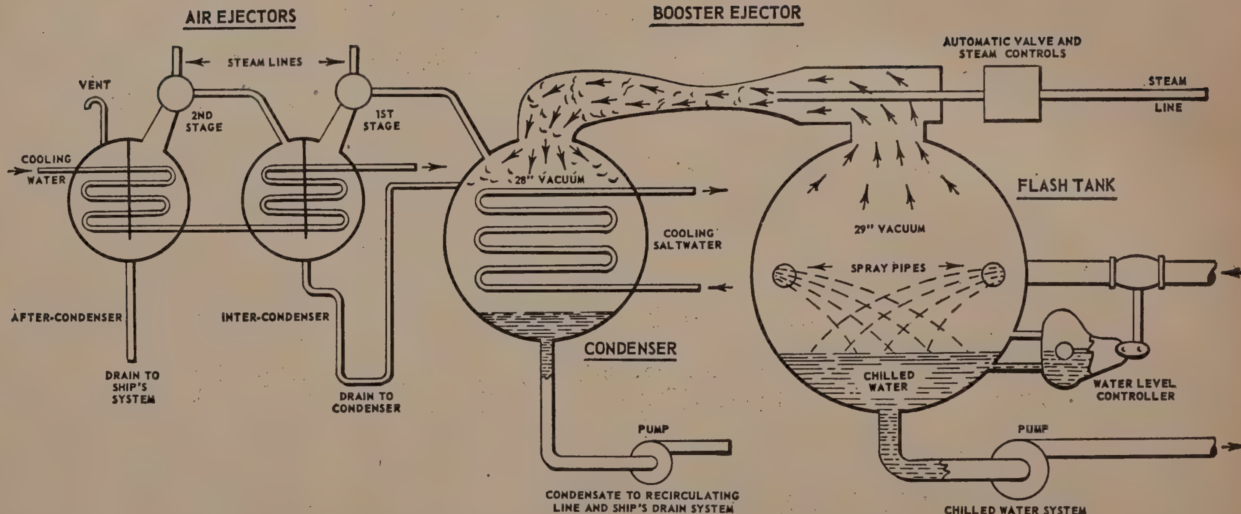


Figure 9–3.—Schematic drawing of the steam jet plant.

tinuously. The booster ejector steam supply is controlled by an automatic valve. The object of this control of operation is to prevent the system from freezing on light loads.

Lithium Bromide Plant

The lithium bromide plant operates on the principle of the absorption cycle. It is a water-cooling plant and is operated by steam. It uses chilled water as the refrigerant and a solution of lithium bromide as the absorbent. Lithium bromide is a desiccant which has the outstanding property of absorbing water.

The major parts of the plant are two shell units, a heat interchanger, an eductor, and pumps. One unit contains the evaporator and the absorber; the other one contains the generator and the condenser. (See fig. 9–4.)

The evaporator consists primarily of a spray pipe and a water tank or receiver. The incoming water is sprayed into the upper half of the shell. Chilled water which has not vaporized is collected by the receiver part and returned to the chilled water system by means of a pump.

The absorber unit consists of a lithium bromide liquid solution spray pipe and sea-water cooling coils. Salt water is pumped through these coils to cool the absorbing lithium bromide. The liquid solution is collected in the bottom of the shell.

The generator consists primarily of a steam coil, which is located in the bottom half of the shell. Steam, supplied by the ship, is passed through the tube nest to boil the lithium bromide in which the tubes are submersed.

The condenser unit is made up of a cooling coil and a condensate receiver or drain tank. Salt water, which is piped from the absorber cooling coil, flows through the tube nest.

The heat interchanger and eductor are of conventional design and operate in a conventional manner.

The chilled water in the lithium bromide plant is sprayed into a chamber within the evaporator in a manner similar to that in the steam jet plant. The shell's being under

vacuum causes a small part of the water to flash into a vapor, which cools the remaining water.

The vacuum is obtained in the shell by spraying a lithium bromide solution over the cooling coils of the absorber unit. The amount of vacuum maintained in the unit depends upon the concentration and temperature of the solution. This solution absorbs the water vapor flashed in the evaporator. The salt-water cooling coil removes the heat of condensation of the water vapor, and the heat of absorption of the solution, from the shell. The proper operation of the shell unit (containing the evaporator and absorber) depends upon a

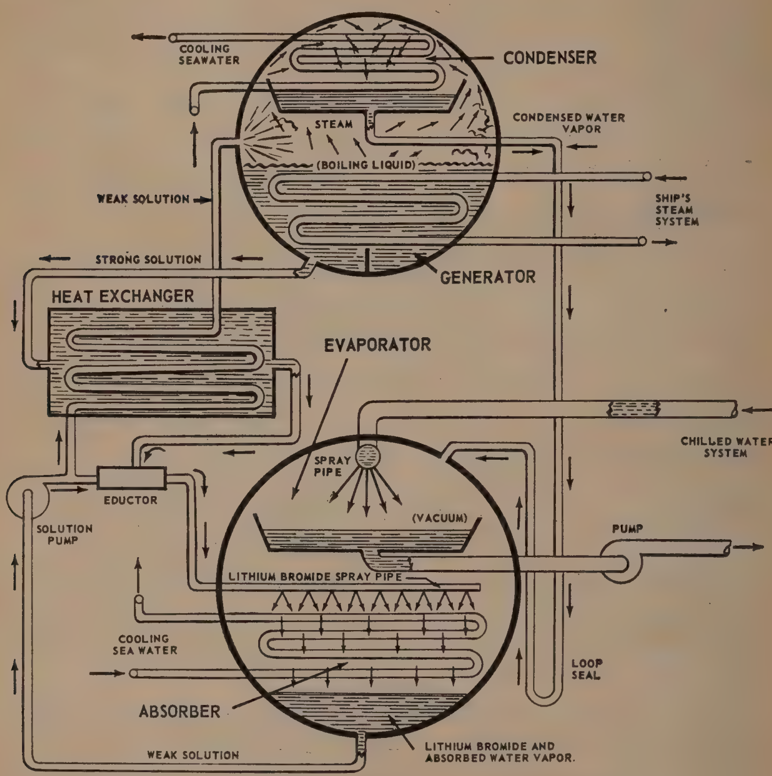


Figure 9–4.—Schematic drawing of the lithium bromide plant.

high vacuum, a strong concentration of the lithium bromide solution, and a low temperature of the solution and shell space.

It should be observed that the above process would very quickly result in the dilution of the lithium bromide solution with the absorbed water from the chilled water system. This dilution would reduce the absorbing action of the solution. Therefore, the water must be removed in order to keep a concentrated solution. This is accomplished by continuously draining part of the liquid from the primary lithium bromide solution system. This liquid is then sent to the generator for the removal of excess water. The diluted or weak solution is boiled in the generator to remove the water. Steam coils are used to heat the liquid in the lower part of the generator shell.

The steam from the boiling liquid is condensed in the upper part of this shell. Salt water is circulated through the condenser to cool the steam and transform it back into water. This water is returned to the evaporator section. The loop seal maintains a difference of pressures between the two shells. The concentrated lithium bromide is returned to the primary circulating system.

The heat interchanger is added to the plant to improve the efficiency and to reduce cooling water consumption. The hot, strong solution will transfer its heat to the cool, weak solution which is to be boiled in the generator. The strong solution must be cooled to prevent it from carrying heat to the absorber unit.

A purge system, which is not shown in figure 9–4, is installed to remove air and noncondensable gases from the plant.

Automatic devices and controls are added to operate or control the various piping systems. Relief valves, gages, and thermometers are also included.

AIR CONDITIONING SYSTEMS

The first air conditioning systems installed on board ship covered only one or two spaces. These were vital spaces,

such as steering engineroom, magazines, CIC, or main plotting station. The Freon–12 plant was used.

New installations of air conditioning cover practically the entire ship except for the main engineering spaces. Besides all vital spaces, berthing, living, and office spaces are air conditioned.

Basic Air Conditioning Cycle

A space gains heat from personnel and equipment inside the space and from heat transmitted through the metal decks and bulkheads. Moisture is added by personnel and any sources of water that may be present in the compartment.

Starting from the space to be cooled the air conditioning cycle (see fig. 9–5) is as follows: The hot, moist air from the space is drawn through a duct, where it mixes with fresh air drawn in from the outside. The fan blows the air over the cooling coil, and the refrigerant inside the coil cools the surface of the coil. These cold surfaces absorb the heat in the

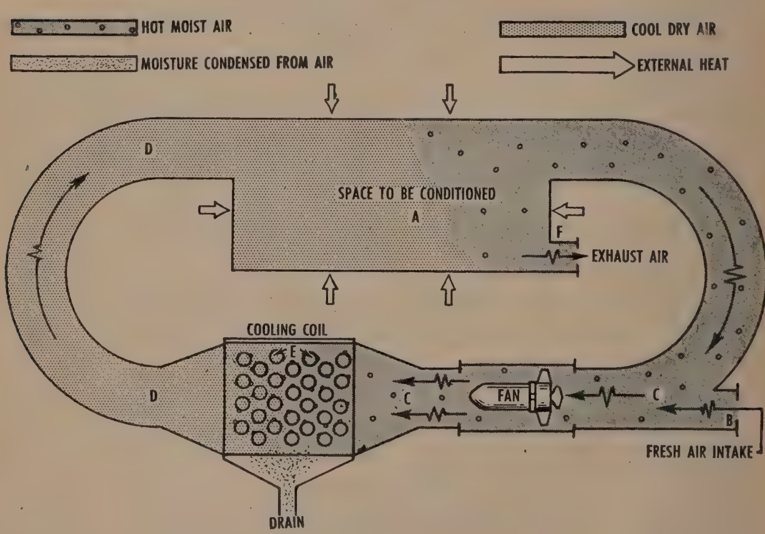


Figure 9–5.—Basic air conditioning cycle.

air passing over it and condense the excess moisture in the air. The moisture drips off into a pan below the coil and is carried away by piping. The cool, dry air leaving the coil is blown into the compartment to be conditioned, where it absorbs the excess heat and moisture in the space. This air is then returned to the cooling coil in a continuous cycle. Air is exhausted from the space to allow for fresh air being drawn into the system.

Shipboard Air Conditioning Cycle

The cooling coil is installed in the ventilation ducts leading to the spaces to be air conditioned. Automatic and manual controls are added to regulate the operation of the air conditioning equipment.

The vital spaces have recirculating units in the compartments. During general quarters, when compartments have been dogged shut and ventilation systems secured, a satisfactory supply of oxygen is maintained by "blowing through" these compartments with fresh air at least every 4 hours, or at the discretion of the damage control officer.

On large ships that have complete air conditioning, the installation is divided into a number of systems. Some such ships have 6 systems which are divided into three "hotel" systems and three vital systems. The ship is divided into three zones—forward, midships, and aft—with one hotel system for each zone. Chilled water is used as a refrigerant medium.

QUIZ

1. What is the chief purpose of air conditioning aboard ship?
2. What is the term used to describe air which, at a given temperature, is holding the maximum possible amount of moisture?
3. If the temperature of the air rises, what effect does this have upon the air's capacity to hold moisture?
4. What is specific humidity?
5. What term is used to mean the ratio of the weight of water vapor in a sample of air to the weight of water vapor that the same sample of air would contain if it were saturated?

6. What type of humidity measurement indicates indirectly the ability of the air to evaporate moisture?
7. Under what conditions will the wet-bulb temperature, the dry-bulb temperature, and the dew-point temperature all be the same?
8. Why does movement of the air within a room generally result in greater comfort for the occupant?
9. What are the ways in which the body may gain heat?
10. For normal body comfort, how should the total body heat loss be divided?
11. What term is used to describe the combined effect of the factors of temperature, humidity, and air motion?
12. What are the acceptable limits of relative humidity, from the standpoint of comfort and health?
13. What kind of a system is the Freon–12 air conditioning plant?
14. Why is an external equalizer used in the Freon–12 air conditioning plant, instead of the internal equalizer which is used in the Freon–12 refrigeration plant?
15. What is the principle involved in the steam jet air conditioning plant?
16. Which of the air conditioning systems used aboard ship operates on the principle of the absorption cycle?
17. Modern air conditioning installations cover the entire ship except for which spaces?
18. When ventilation systems are secured during general quarters, how often must fresh air be blown through the compartments that have been dogged shut?
19. Aboard large ships which have an air conditioning installation divided into 6 systems, where are the "hotel" systems?
20. In these large installations, what is used as the refrigerating medium?

CHAPTER 10

DIESEL ENGINES

Diesel engines are used in the Navy for main propulsion of submarines and surface ships; for ship's service and emergency generators; for vital auxiliaries; and for ships' boats. Diesel engines used as main propulsion power for tugs range from 250 to 3,000 hp; for submarine chasers, from 800 to 1,800 hp; for patrol craft and minesweepers, up to 3,000 hp; for seaplane tenders, up to 6,000 hp; for escort vessels, from 6,000 to 12,000 hp; and for auxiliary ships and tenders, up to 12,000 hp.

ENGINE TYPES

Diesel engines may be divided into several classes, using different bases for the division: (1) operating cycle, (2) cylinder arrangement, (3) piston action, (4) speed, etc. However, those in the naval service are usually classified by their operating cycle (four-stroke cycle and two-stroke cycle).

The FOUR-STROKE-CYCLE ENGINE requires four strokes of the piston, or two revolutions of the crankshaft, to complete one cycle; that is, there is one power stroke in every four strokes of the piston. (The operating sequence is given in the Navy Training Course, *Fireman*, NavPers 10520.)

TWO-STROKE-CYCLE ENGINES are widely used by the Navy. In this type engine the cycle is completed in two strokes of the piston, or one revolution of the crankshaft. A basic difference between the two-stroke and four-stroke engines is the

method of removing the burned gases and filling the cylinder with fresh air.

STATIONARY PARTS

The main stationary parts of a Diesel engine are designed to maintain the moving or working parts in their proper relative positions so that the gas pressure produced by the combustion is used to push the piston and rotate the crankshaft.

Engine Frame and Crankcase

Modern high-power-output engines have frames welded of steel, with plates located at places where the loads occur. (See fig. 10–1.) The customary arrangement combines the

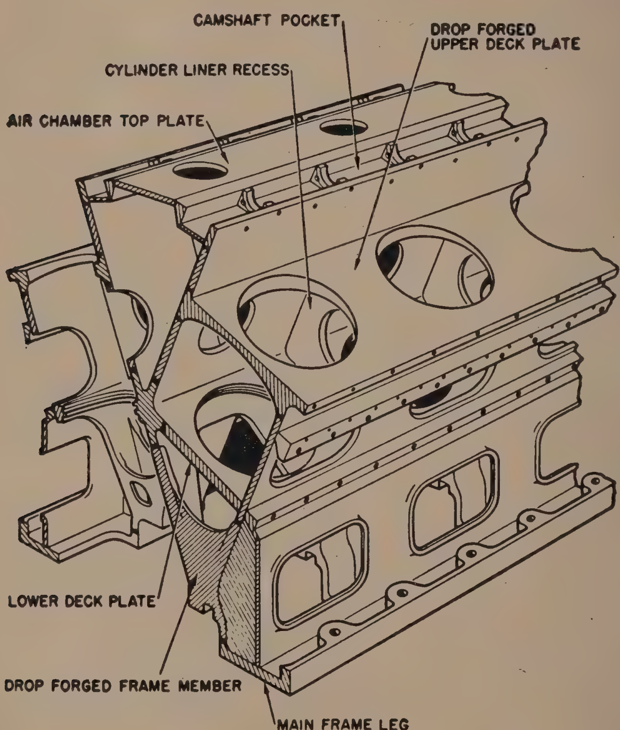


Figure 10–1.—Sectional sketch of a GM welded frame.

cylinder block with the main bearing supports, although a separate crankcase section is sometimes used. Access doors are provided at every cylinder to permit assembly and observation of the bearings.

Cylinders

The working space (the space where combustion takes place), is formed by the cylinder and the cylinder head. The diameter of the cylinder is known as the bore. The other end of the working space of the cylinder is sealed by the piston. A gastight seal between the piston and the cylinder liner is obtained by piston rings.

The cylinder liner is made of a material which will enable the piston and rings to move up and down with minimum friction. It is usually made of cast iron, although porous chromium plated steel sleeves are sometimes used.

Cylinder Heads

The cylinder head, usually a casting of alloy iron, seals the combustion chamber and, in most engines, contains the valves and passages for intake and exhaust gases, the fuel injection nozzle, the air starting and relief valves, and passages for the cooling water from the cylinder jacket. Both the cylinder and cylinder head have to be water-cooled because of the heat in the combustion chamber. This cooling prevents excessive temperatures, which might crack the head and which would interfere with the operation of the fuel injection nozzle and all valves. Large-bore engines have individual heads for each cylinder, while small-bore engines may have a single head covering all cylinders or pairs of cylinders.

Crankshaft Bearings

Most modern Diesel engines, regardless of size and speed, have precision bearings which are separate from the saddles and connecting rods. They consist of thin steel, bronze, or brass shells, with a lining of bearing metal, which is gen-

erally not more than $\frac{1}{32}$ in. in thickness. The bearing metal may be one of several types which have proved satisfactory: lead-base babbitt, copper-lead, cadmium-silver, solid aluminum, etc.

MAIN MOVING PARTS

The main moving parts of a Diesel engine are those units that convert the heat energy in the cylinders, by combustion of the fuel, to mechanical energy that is delivered to the drive shaft. These parts are so arranged that reciprocating motion is changed into rotary motion. Main moving parts may be divided into three major classes: (1) parts having rotary motion, (2) parts having reciprocating motion, and (3) parts having both rotary and reciprocating motion.

Crankshaft

The forces acting on a Diesel engine crankshaft are high because of the high firing pressure and the inertia of the moving parts. The main requirements of a crankshaft are mechanical strength, and static and dynamic balance. Crankshafts are relatively large in diameter and are supported by main bearings between each pair of cranks.

Many shafts are drilled (through the crank webs) to admit pressure lubrication from the main bearings to the crankpins. Most crankshafts of Diesel engines are forged from high-strength alloy steel; however, high-tensile cast-iron crankshafts are being used in various types of modern Diesel engines. Most of the small forged steel shafts are surface-hardened by heating the surface electrically and then quenching it with sprays of water.

Pistons

Pistons of single-acting engines usually are of the trunk type. They must carry pressures varying from a slight vacuum to about 1,500 psi (peak pressures). Pistons must withstand (1) expansion stresses resulting from fluctuations

in temperature, and (2) high bearing and side-thrust loads resulting from contact of the piston with the cylinder liner.

Pistons are usually cast, because it is relatively easy to provide satisfactory ribbing on the interior in a casting and still keep the weight low. However, forged and welded steel pistons are used with some engines. Generally, the piston is cooled with lubricating oil sprayed from the connecting-rod cap under the crown of the piston. Many high-speed engines have aluminum pistons, but the trend is toward pistons of cast iron with very thin walls, which are cooled by lubricating oil. The cast-iron pistons have the decided advantage of having the same coefficient of expansion as the cylinder liner.

All of the load developed in the cylinder passes through the wrist or piston pin, which is the only connecting link between the piston and the connecting rod. Most wrist pins are supported at both ends by bronze bushings in the piston bosses and are maintained in place by caps which are fitted to each side of the piston. The connecting rod swings on a bronze bushing or needle bearing at the center of the pin. In some engines the wrist pins are locked in the piston at the ends. There is still a third type of wrist pin, supported at both ends by bronze bushings in the piston bosses and clamped in the middle of the connecting-rod end. Wrist pins are made of high-strength alloy steel and must have a fine-finished, hardened surface in order to obtain good bearing action.

COMPRESSION RINGS are inserted at the top of the piston. They seal the space between piston and liner, thus preventing the high-pressure combustion gases from escaping; they also damp out part of the fluctuations of the piston side-thrust. These rings are made of grey cast iron; some have special facings to facilitate seating into the liner.

The OIL SCRAPER OR OIL CONTROL RINGS are located at the bottom end of the piston. Their purpose is to scrape off most of the lubricating oil splashed upward by the crankshaft, thus reducing the amount of oil carried upward and burned in the combustion chamber. At the same time they must allow sufficient oil for proper lubrication of the cylinder.

The type of compression ring most widely used has a rectangular cross-section. The diameter of the free ring is slightly larger than the cylinder bore, and this difference in diameters produces a pressure against the liner wall. The pressure of the upper rings is increased by the action of the gases. The combustion gases enter behind the ring, through the vertical clearance which always exists between a ring and its groove, and force the ring against the cylinder liner.

Some engines have compression rings the bottom wall or both walls of which are beveled. The gas pressure acting on the top wall, because of the beveled surface, produces an additional force pressing the ring against the cylinder wall. At each reversal of the side thrust of the piston, the ring slides slightly into the groove, crushing carbon deposits; this keeps the ring from sticking. Some engines use bimetallic rings in which the cast-iron wearing face is brazed to a steel inner ring to obtain increased strength.

Oil control rings have a narrow face so as to obtain a higher unit wall pressure, and are often undercut to give a scraping edge. The piston has rows of holes drilled in it for draining the oil through the bottom of the ring grooves. The oil scraped by the ring must be drained off immediately; otherwise it will build up a pressure which will force the ring back into its groove and stop the scraping action. Spring-steel expanders are sometimes used behind the rings to increase their pressure against the cylinder wall and thereby improve the scraping action.

The gap between the ends of the rings must be sufficiently large so that when the ring expands the ends will not be pressed together and buckle the ring. Most rings have the ends cut square.

To prevent oil control rings in two-stroke engines from catching in the cylinder ports over which they slide, the ends are sometimes notched and a pin is installed in the piston ring groove to hold the ring ends in line with a bridge between the ports.

Connecting Rods

Connecting rods in Diesel engines are similar to those used in automobile engines. They have an eye at the small end for the piston pin bearing, a long shank, and a big end opening which is split to receive the crankpin precision bearing shells. The rods are forged of a high-strength alloy steel. Most connecting rods are rifle-drilled from the big end to the eye, so that oil may flow from the crankshaft bearing to the wrist pin bearing.

VALVE GEAR

The combination of those parts which control the admission of the air, the discharge of exhaust gases, the admission of fuel, and the admission of compressed air, is called valve gear.

Cams and Camshaft

Most cams are forged as a part of the camshaft, as in the case of automobile engine camshafts. Thus, if one cylinder is timed correctly, all are; and any change in timing will affect all cylinders. The shape of the cam determines the points of opening and closing of the valve, the speed of opening and closing, and the amount of valve lift.

The camshaft is carried in plain bearings and is driven by the engine crankshaft. Most engines have a train drive of spur gears. In two-stroke engines the camshaft rotates at the same speed as the crankshaft, while in four-stroke engines it rotates at half the crankshaft speed. Most camshafts are made of forged steel, usually nickel-chromium alloy steel. They are heat-treated, and in some cases the cams are surface-hardened.

Cam Followers

Modern Diesel engines use several types of cam followers, among which are the flat or mushroom follower, the roller-type follower, and the pivoted follower.

The rollers of the followers are made of steel, hardened and accurately ground to size and to a true circle.

Rocker Arms and Push Rods

The rocker arm has one end in contact with the top of the valve stem and the other end, by means of a hardened-steel roller, is in contact with the rotating cam. (If the camshaft is not located near the cylinder head, the rocker arm is in contact with the end of a push rod.) Figure 10–2 shows the valve-actuating gear.

Types of Valves

Four types of valves are used in Diesel engine heads: exhaust, intake, air-starting, and fuel-injection. All of these valves, however, are not found on every engine. Engines using electrical starting do not need an air-starting valve; and some engines use ports instead of valves.

Valves are all of the so-called poppet type. These valves have beveled edges, which give them a self-centering action. Bevel seats ground at an angle of 45° have proved to give the best service.

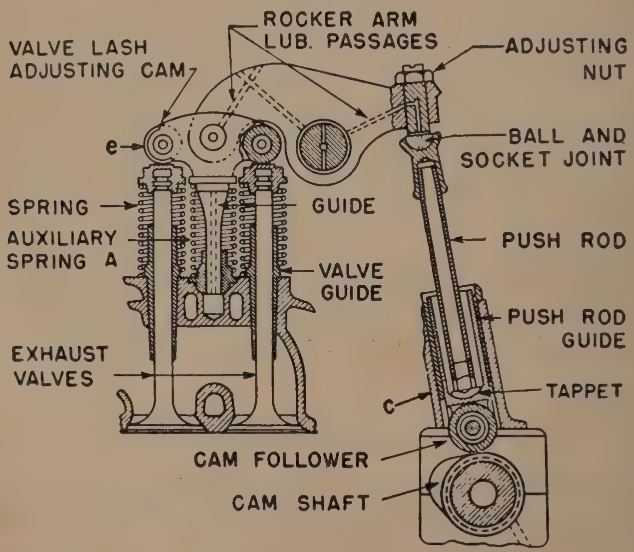


Figure 10–2.—Winton engine valve-actuating gear.

Exhaust valves are made of silicon-chromium steel or other alloy steel to resist the corrosive action of high-temperature gases. Inlet valves are usually made of low-alloy steels.

Most Diesel engines have fuel-injection valves set into the heads so that the tip of the nozzle is free to inject fuel into the combustion chamber. The valve must be cooled while the engine is running and it must be easily removable for cleaning and overhaul. In some engines the fuel nozzle is sealed into a water-cooled copper tube.

Valve Inserts and Bushings

In order to increase the service life of exhaust-valve seats, it is common practice to employ valve-seat inserts made of alloys which resist the high temperatures found under operating conditions. Valve-seat inserts consist of rings which fit into counterbored recesses in the valve port openings.

Because of the continuous up-and-down motion of the valve stems the guide holes are subject to considerable wear. In order to control this wear, easily renewed bushings are inserted in the guide holes to act as valve guides.

Valve Springs

The valve spring which serves to close the valve is made of round steel wire, wound in a helical coil. The principal functions of the valve spring are (1) to provide sufficient force to close the valve, and (2) to keep the valve gear in contact with the cam without bouncing.

Valve Lash and Adjustment

The expansion of the valve stem, when the engine heats up, has a tendency to hold the valves off their seats. The most common method used to control this condition is to provide a clearance or lash between the top of the valve stem and the valve-lifting mechanism. Too much lash will result in improper valve timing, noisy operation, and exces-

sive wear; too little lash is even more serious since it may prevent the valve from seating properly, with resultant valve leakage and burning of the valve-seating surfaces.

All engines are provided with means for adjusting the clearance in the valve gear. In most engines this consists of an adjustable screw and lock-nut located at one end of the valve rocker arm. The clearance is measured by means of a feeler gage.

Automatic valve-lash adjusters are used (1) to avoid the necessity of a clearance between the cam and the follower by ensuring a constant contact in the valve gear at all times, and (2) to eliminate the shock action of valve opening. They also eliminate the need for manual adjustment. There are two types of automatic adjusters, mechanical and hydraulic.

The mechanical valve-lash adjuster is incorporated in the valve bridge, as shown in figure 10–2. A spiral spring has a tendency to turn the valve-lash adjusting cam clockwise when the cylindrical spring (A) pushes the bridge to its highest position. The spring (A) takes up any clearance between the various parts of the valve-actuating gear, and

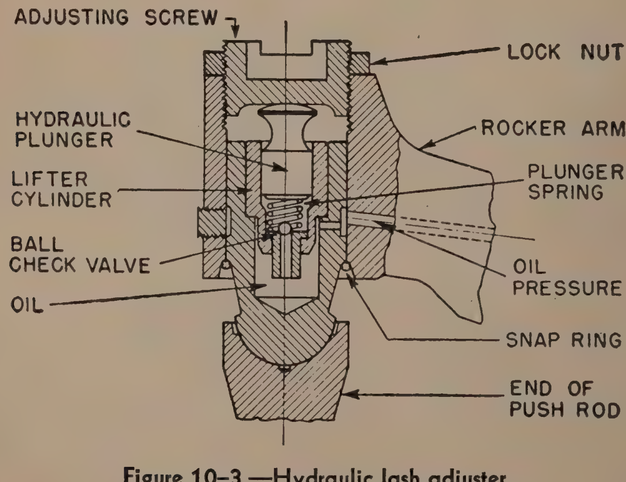


Figure 10–3.—Hydraulic lash adjuster.

the turning of the cams (e) takes up the clearance between the ends of the bridge and the valve stem.

Hydraulic valve-lash adjusters may be built into the valve tappets, but with valve-in-head engines they are generally built into the end of the rocker arms. Such an adjuster is shown in figure 10–3.

The hydraulic valve-lash adjuster consists essentially of a small cylinder, containing a piston, a spring, and a ball check valve. In operation, oil under pressure, from the lubricating oil system, enters the cylinder past the ball check valve and is trapped under the plunger. Any force exerted against the outer end of the plunger will be transmitted to the push rod by the entrapped oil. The valve is thus actuated just as if the lash were taken up mechanically. Since the spring acts to force the plunger outward, any clearance between the valve and its lifter will be taken up, and the oil under pressure will fill the lifter cylinder. If the valve stem expands, there is sufficient leakage of oil past the plunger to permit it to move in slowly; there is, therefore, no danger of holding the valve open.

FUEL SYSTEM

The fuel injection system, in delivering the fuel to the combustion chamber, must fulfill the following main requirements:

1. Meter or measure the correct quantity of fuel injected.
2. Time the fuel injected.
3. Control the rate of fuel injected.
4. Atomize the fuel or break it up into fine particles.
5. Properly distribute the fuel in the combustion chamber.

The first system which adequately met these requirements was the AIR-INJECTION system. Air injection was utilized by the first successful Diesel engines (about 1900) and was universally employed until about 1930. However, air injection was superseded by MECHANICAL or SOLID INJECTION, and

since about 1935 very few engines have been constructed with air-injection fuel systems.

Mechanical or solid injection systems may be subdivided into three main groups: common-rail, individual-pump, and distributor systems.

Common-Rail System

This system consists of a high-pressure constant-stroke constant-delivery pump which discharges into a common-rail (or header) to which each fuel injector is connected by tubing. A spring-loaded bypass valve on the header maintains a constant pressure in the system, returning all excess oil to the fuel supply tank. The fuel injectors are operated mechanically, and the amount of oil injected into the cylinder is controlled by the lift of the fuel-admission valve (see fig. 10–4).

The fuel cam transmits a motion to the push rod, rocker arm, and lever which lifts the needle valve. The space above the needle valve seat is connected at all times with the fuel header and sealed from the top by a packing gland. When

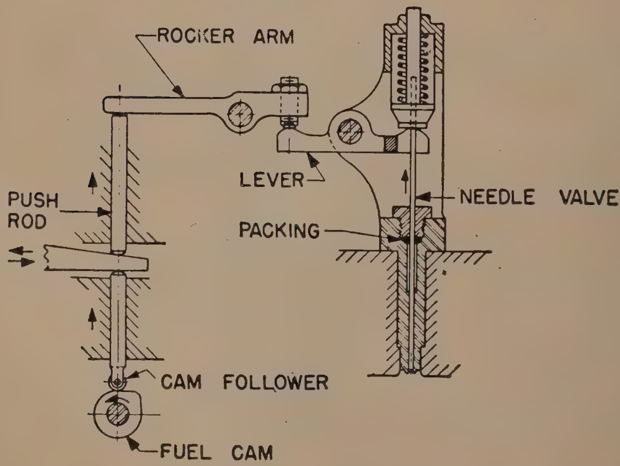


Figure 10–4.—Control of fuel admission in a common-rail system.

the needle valve is lifted from its seat, the fuel is admitted to the combustion space through small holes drilled in the injector tip. Passing through these tiny holes, the fuel is divided into small streams which are broken up or atomized.

The amount of fuel injected is controlled by means of the wedge shown in figure 10–4, which changes the lash of the fuel valve. When this wedge is pushed in or to the right, the valve lash is decreased. The needle valve will be opened earlier, closed later, and its lift will be slightly greater. Therefore more fuel will be admitted. When this wedge is pulled out the needle valve will be lifted later and closed earlier, and less fuel will be admitted. The position of the control wedge is changed either by the governor or by hand. The fuel-injection pressure is adjusted by changing the spring pressure in the bypass valve called the fuel-pressure regulator.

To reduce pressure fluctuations due to the intermittent fuel discharge from the pumps and withdrawals by the fuel valves, the volume of the fuel in the system is increased by attaching to the fuel header an additional fuel container called the accumulator.

This system is not suitable for high-speed small-bore engines, because it is difficult to control accurately the small quantities of fuel required by these engines.

Pump-Injection System

This system, also known as the jerk-pump system, has two essential parts for each cylinder: the injection pump and the fuel nozzle. The requirements which a pump in this system must fulfill, both in respect to metering and timing, are such that they can be met only by a precision piece of equipment.

In operation on a high-speed Diesel engine, these injection pumps accurately measure and deliver, under high pressure and at exactly the required time, exceedingly small quantities of fuel.

All injection fuel pumps of the jerk-pump type have

plungers which are fitted closely to the pump barrels by lapping. The plungers are fitted to their barrels by selective assembly from plungers and barrels which have been lapped truly round and cylindrical but differ slightly in diameter. In this way a fit is obtained with a clearance less than 0.0001 inch; such a fit gives very little leakage, even with the high pressures created, and no packing of any kind is necessary. (These parts are not interchangeable.)

Fuel oil, like all liquids, is in a sense compressible. When the pump plunger, at the beginning of the actual delivery, strikes the oil in the pump barrel, the oil is not accelerated at once in the whole fuel line. The initial blow of the plunger sets up a compressive wave in the fuel line. When this wave reaches the nozzle it is reflected back to the plunger; this results in a certain amount of oscillation of compressive waves in the fuel lines. These disturbances are particularly noticeable in engines operating at variable speed. The pressure waves may produce vibration of the tubing which connects the pump and the nozzle.

JERK PUMP.—In order to obtain proper atomization a high pressure must be maintained in the fuel line, from the very start to the end of the injection period. Since this pressure is proportional to the plunger speed, the latter must be reasonably high during the whole injection period. The high pressure is obtained by discarding, for the fuel delivery only, the initial part of the stroke and using that part of the plunger stroke in which the plunger has acquired a predetermined speed. This procedure produces a sudden acceleration of the fuel in the line, resulting in a jerk—hence the name jerk pump.

In most jerk pumps, the over-all plunger stroke is fixed; and the metering is controlled by varying the length of the effective part of the plunger stroke by one of the following methods:

1. The fuel is admitted into the pump barrel through ports, in the barrel, CONTROLLED BY A SPIRAL GROOVE OR SCROLL (ALSO CALLED THE HELIX) ON THE PLUNGER. The plunger can be turned in the barrel, while moving back and forth, to

change the portion of the plunger stroke during which the ports are covered and the fuel is delivered to the nozzle.

The principle of plunger-controlled pumps may be understood by referring to figure 10–5. At the bottom of the plunger stroke (a) the suction and pressure release ports are both in communication with the inner pump space. When the plunger has moved far enough to cover both ports, fuel delivery begins with a jerk, and lasts until the lower edge of the spiral begins to uncover the release port (b). At this point the pressure drops and fuel delivery stops. The plunger continues to travel a short distance to the top of its stroke and then begins to move downward. If the plunger is turned about 60°, as in (c), the distance between the top edge of the plunger and the edge of the spiral sliding over the release port is shorter, and the fuel delivery stops earlier. Finally, if the plunger is turned 90° more, the release port stays uncovered, and no fuel is delivered.

2. The fuel is admitted into the pump barrel through ports in the barrel, which are CONTROLLED BY A SEPARATE VALVE.

In valve-controlled pumps, the pump plunger has a constant stroke and operates in a plain cylinder. The fuel delivery is controlled by a rotary valve with a wedge-shaped

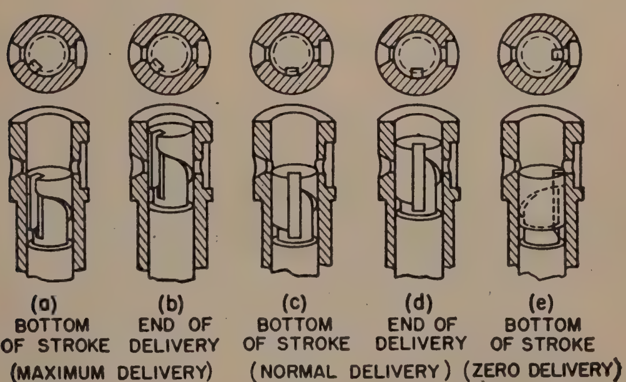


Figure 10–5.—Barrel with various plunger positions.

end. (See fig. 10–6.) When the plunger, traveling to the left, approaches its middle position, the rotary valve closes the admission port by moving the slanting fuel-cut-in edge across it. When, due to rotation of the valve, the other slanting edge reaches the port the inside of the pump comes in communication with the low-pressure space, the pressure is released, and fuel delivery is cut off. The rotary valve can be moved axially, by the governor or by hand; this movement changes the distance FROM THE CUT-IN TO THE CUT-OFF SLANTING EDGE and thereby changes the duration of the fuel injection period.

The plunger of a valve-controlled pump is operated by a cam during the delivery stroke and is returned by a spring. The pumps are built either as separate units for each engine cylinder, or as a multiplunger in-line unit for all cylinders.

Pumps of this type can be conveniently built around a rotary valve (see fig. 10–7). The individual pump units are

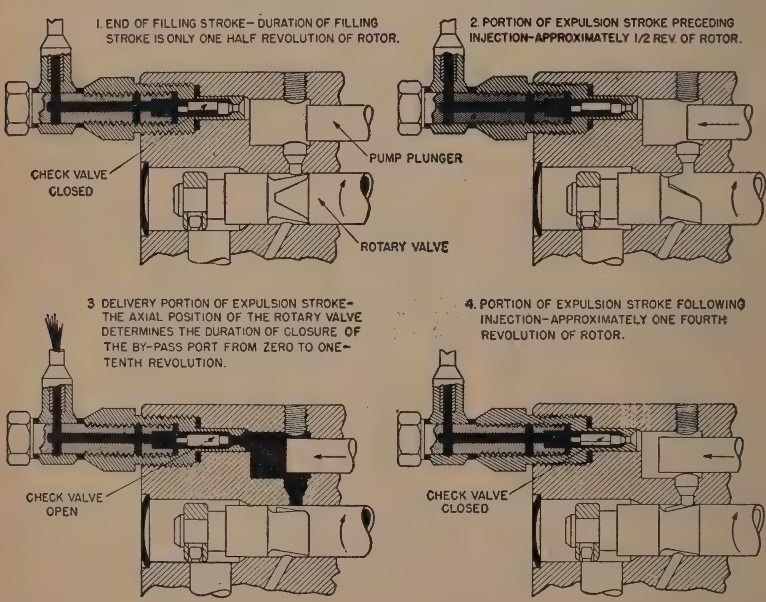


Figure 10–6.—Jerk pump with rotary bypass valve.

located in a circle around the centrally located rotary valve. A swash plate (also called a wobble plate) is used as the driving member. By the use of shoe-plates containing sockets the rotary motion of the swash plate is converted into a straight-line back-and-forth motion which operates each pump plunger. The plungers are returned by springs.

Fuel Nozzles.—The closed-type nozzle is most commonly used. This nozzle consists basically of an hydraulically operated, spring-loaded needle valve. Most closed-type nozzles open inward under the pressure acting on the differential area of the needle valve, and are seated by a spring when the pressure is cut off. The larger cylindrical part of the valve has a lapped fit with the nozzle body. There are two main types of such nozzles: the pintle-type and the hole-type.

The valve of the pintle nozzle is provided with a pin, or pintle, which protrudes from the hole in the bottom of the nozzle, in which the pin fits closely. The fuel delivered by this nozzle must pass through an annular or ring-shaped orifice; the spray is in the form of a hollow cone. An important feature of the pintle nozzle is its self-cleaning property, which prevents carbon deposits from building up in and around the orifice.

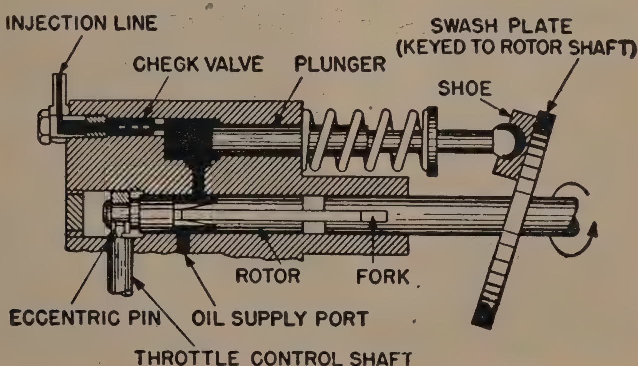


Figure 10–7.—Section of Ex-Cell-O pump.

The hole-type nozzle may have one or several spray orifices, in the form of straight, round holes drilled through the tip of the nozzle body below the valve seat. The spray from the single-hole nozzle is relatively dense and has a great penetration. The spray pattern of a multihole nozzle is determined by the number, size, and arrangement of holes.

Unit Injector

The unit injector combines a pump and a fuel-spray nozzle in one unit, as shown in figure 10–8. The pump is of the jerk

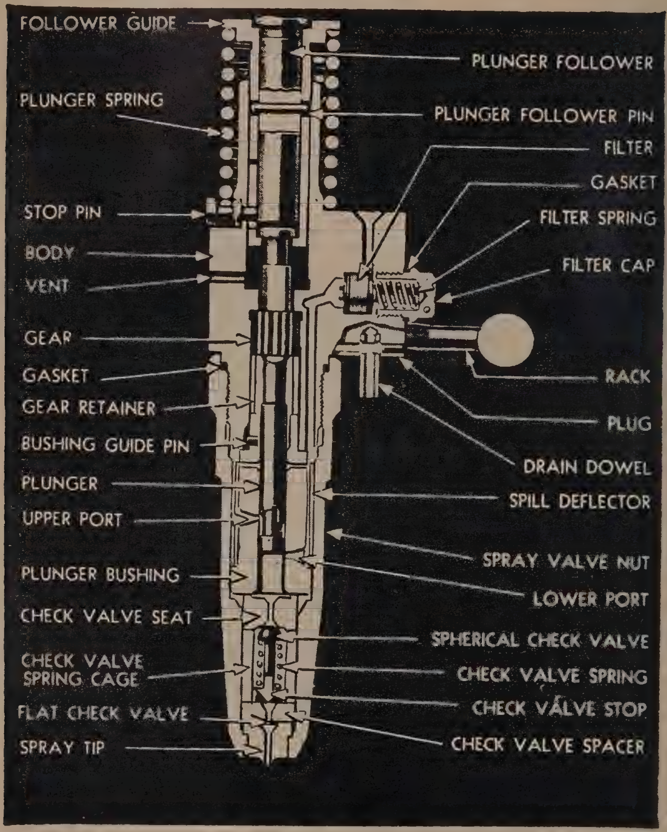


Figure 10–8.—Unit injector with spherical check valve.

type with the ports controlled by helical-grooved edges in the plunger. The amount of fuel is controlled by turning the plunger.

The pump plunger receives its downward motion, the delivery stroke, from a fuel cam through a rocker arm which acts on the plunger follower. The plunger is returned by the plunger spring. The fuel, under pressure of about 35 psi, is admitted through a small filter and fills the annular supply chamber around the pump plunger bushing. As the plunger moves downward fuel is displaced into the supply chamber—at first through the lower port, and later, when the lower edge of the plunger closes this port, through a central and a transverse port or crosswise drilled holes in the plunger and upper port. When the upper helical edge has covered the upper port, the fuel from the pump plunger barrel is forced down into the nozzle body (opening the spherical check valve) past the flat check valve, and into the spray tip. From there it is forced through the orifices into the cylinder. The fuel-injection pressure is raised very high as the fuel passes through the nozzle. Injection continues until the lower helix on the plunger uncovers the lower port in the plunger barrel. The fuel then begins to bypass, through the holes in the plunger and through the lower port, into the supply chamber; this releases the pressure on the fuel in the plunger barrel, and the check valve spring causes the spherical check valve to seat.

On the return stroke, the upward movement of the plunger fills the plunger barrel with fuel oil which flows from the supply chamber through the lower port. The only function of the flat check valve is to close the inside of the nozzle against gases from the cylinder.

Turning the plunger in order to change the effective length of the stroke is accomplished by a gear-and-rack connected either to the governor or to the hand throttle. The middle part of the plunger has an hexagonal cross section which slides through a corresponding hole in the gear, thus forcing the plunger to turn with the gear. The effective stroke is

determined by the relative position of the helices and the upper and lower ports.

Distributor System

There are several distributor systems used in the different makes of engines. One common system is shown in the schematic drawing, figure 10–9. Although essentially a distributor system, this system has the characteristic features of a unit injector. In this system, fuel under pressures of 130 to 150 psi is supplied by a gear transfer pump. The oil then passes through an indexed rotating distributor to a metering plunger (during its downward stroke). This plunger has a variable stroke, controlled by the governor, and receives its upward motion from a multilobe cam and the downward motion spring. During the upward stroke, this plunger sends the fuel, through other passages in the same distributor, to the individual injectors on each engine cylinder. The fuel enters at the top of the injector and flows, through an inlet passage, past a spring-loaded check valve. The injection plunger is operated by a cam, through a rocker lever and link. As the fuel is delivered from the distributor to the injector during the suction stroke of the engine, the injector plunger is gradually lifted and the fuel fills the space in the cup under the plunger. At the time of injection the plunger is pushed downward and the fuel which is prevented, by the check valve, from returning to the distributor is injected into the combustion space.

LUBRICATION SYSTEMS

All modern engines are lubricated under pressure. A lubricating oil pump forces the oil through the engine and accessory parts at a pressure of from 30 to 50 psi. In order to maintain the required oil pressure, regulating valves and relief valves are installed in the system. The principal parts of the lubricating oil system are the pump, cooler, filter, and strainer. These parts are all shown in figure 10–10.

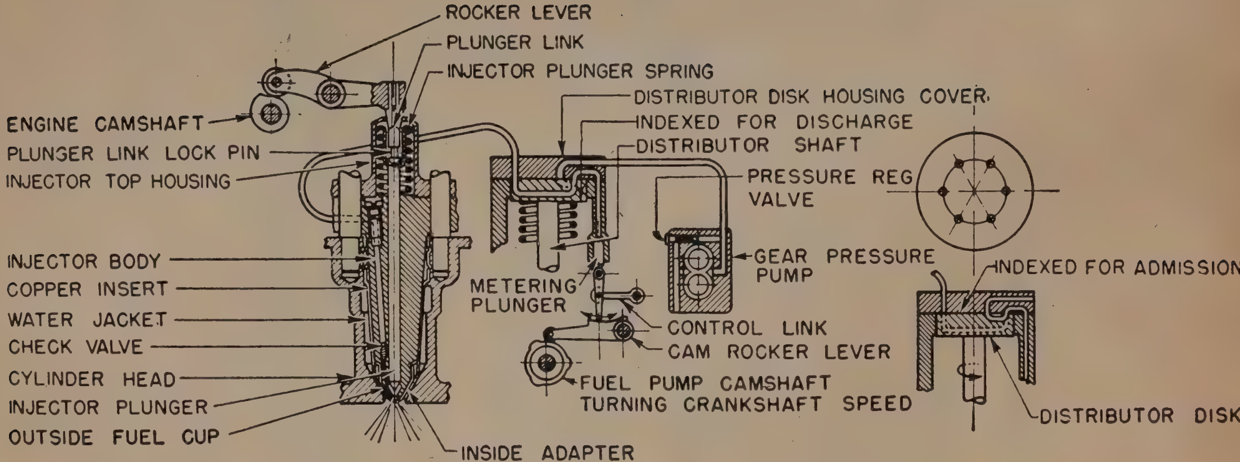


Figure 10–9.—Cummins distributor-type low-pressure fuel injection system.

Typical Lubrication System

The lubrication system of a small engine is easily understood, yet it has most of the parts that are found in the lubricating systems of larger, more complex engines.

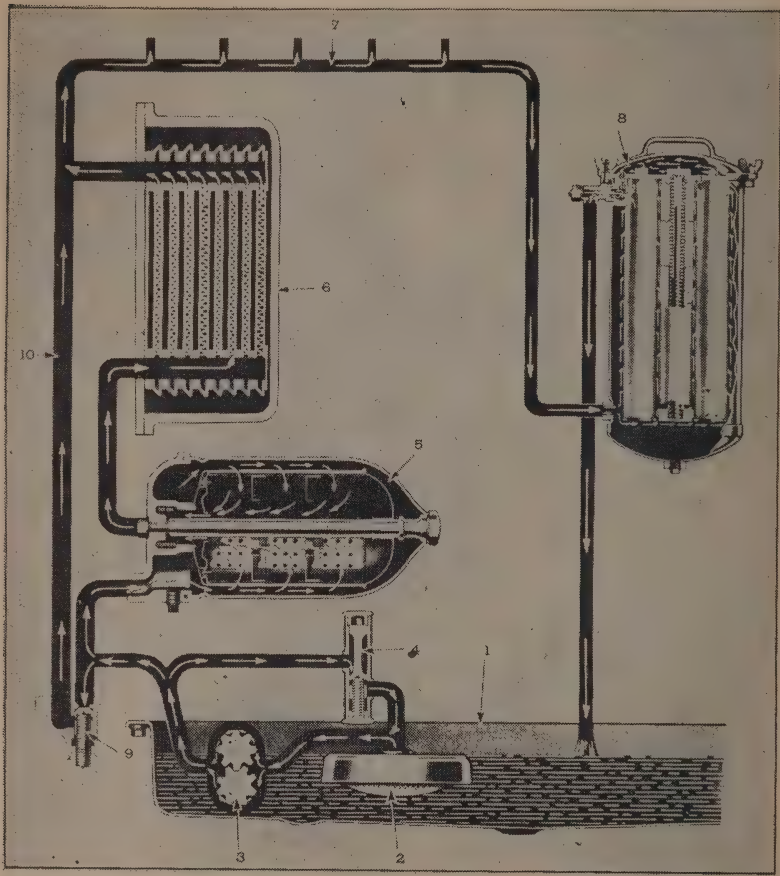


Figure 10–10.—Schematic diagram of the oil circuit in a GM 2–71 engine.

1. Oil Pan.
2. Screen—Oil Pump Intake.
3. Pressure Oil Pump.
4. Valve—Pressure Relief.
5. Oil Strainer.
6. Oil Cooler.
7. Oil Manifold in Cylinder Block.
8. Oil Filter.
9. By-Pass Valve.
10. By-Pass Around Strainer and Cooler.

The gear-type pump draws the oil through the oil inlet screen. This screen has a coarse mesh and serves to catch only large foreign particles.

The positive displacement pump has two meshing gears rotating inside a close-fitting case. Oil is pumped by being caught between the teeth of the gears and the casing as the gears revolve. It then goes to the oil strainer and passes through small pores which strain out all particles larger than .005 in. The oil then flows to the oil cooler. Next the oil enters the main oil gallery in the cylinder head. All this oil, however, does not actually flow through the engine; some of it is bled off to the oil filter, where impurities from engine operation are removed. This filtered oil returns directly to the crankcase.

In figure 10–11, the oil passages within an engine are shown by diagonal white lines. From the cooler the oil enters a vertical passage in the forward end of the cylinder block, and flows two ways: upward to the main oil gallery and downward to the forward main bearing. The downward flow also lubricates the forward camshaft and the balance shaft bearings. From the forward main bearing, the oil goes through a drilled passage to the adjacent connecting rod bearing. From the connecting rod bearing the oil continues up through the drilled connecting rod to lubricate the piston pin. The oil is then sprayed as a cooling liquid against the piston crown. Oil also sprays from the connecting rod bearing to lubricate the cylinder liner; it then flows by gravity directly back to the crankcase.

From the main oil gallery the oil flows downward through two passages to the center and rear main bearings. Oil from the center vertical passage lubricates the center camshaft bearing, the center main bearing, the rear connecting rod bearing, and the rear piston assembly. The oil that passes down the rear vertical passage, in addition to lubricating the rear main bearing, also lubricates the rear bearings of the camshaft and balance shaft. The rocker arm assembly is lubricated by upward flow from the main gallery. The rocker shaft is secured to the head by hollow bracket bolts;

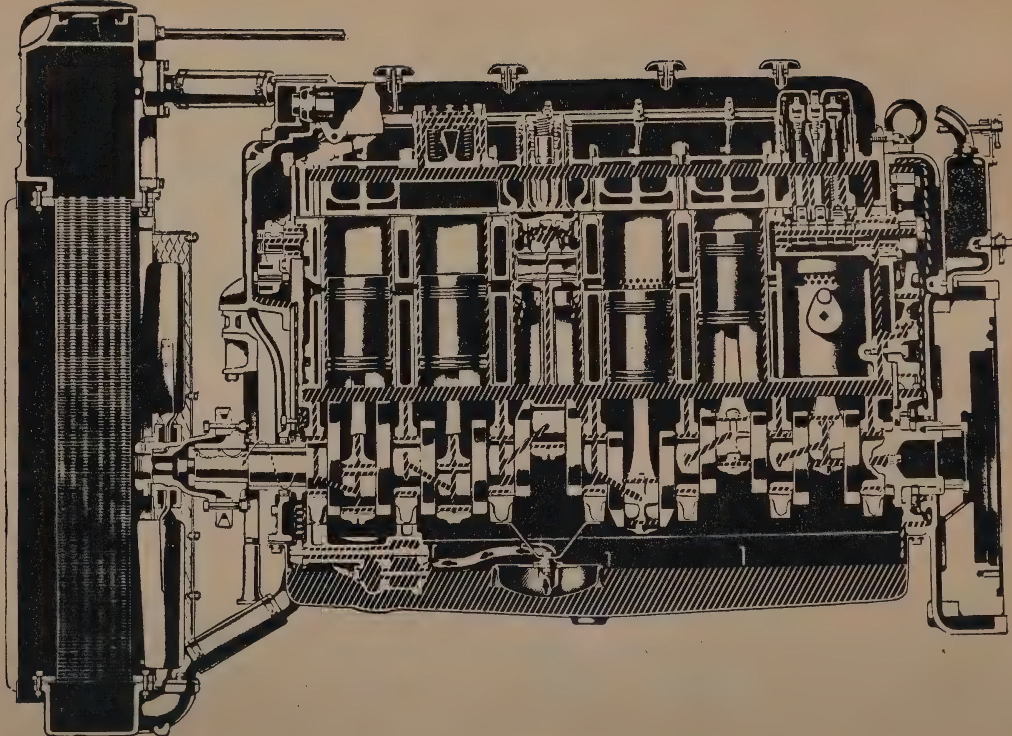


Figure 10–11.—Diagram of an engine lubrication system.

the hollow passages in these bolts are drilled through to the main oil gallery. Oil flows through the hollow bracket bolts into a drilled passage in each rocker shaft, and feed holes in each rocker shaft supply oil to each rocker arm bushing. Excess oil from the rocker arms lubricates the exhaust valves, injectors, and the entire push rod mechanism. The drain passages from the cylinder head are so arranged that the oil lubricates the gear train, blower gears, and blower bearings as it flows, by gravity, back to the crankcase.

COOLING SYSTEMS

Cooling must be provided for Diesel engines, mainly for the following reasons:

1. To prevent breakdown due to overheating of the lubricating oil film.
2. To prevent loss of strength due to overheating of the metal engine parts.
3. To prevent excessive stresses in or between the engine parts, due to unequal temperatures within the engine.

The cooling medium used is either water or air. Marine Diesel engines use water. The water should not contain any impurities which might form deposits on the inside of the engine water passages and thus impair the heat transfer. For this reason, fresh water which has been treated to remove scale-forming impurities is used almost universally as the coolant for the Navy's marine Diesel engines.

Salt-Water System

A salt-water pump draws water from the sea chest through a strainer and the reverse gear oil cooler. The sea water is discharged from the pump to an air cooler, in which air for the engine intake is cooled. The water is next piped to the lubricating oil cooler. It then circulates through the jacket water cooler, in which the fresh water is cooled. Finally, the sea water passes through a water jacket around the exhaust manifold and is discharged overboard. Figure 10–12 illustrates the basic cooling system.

Several designs of oil coolers are in use, but the principle

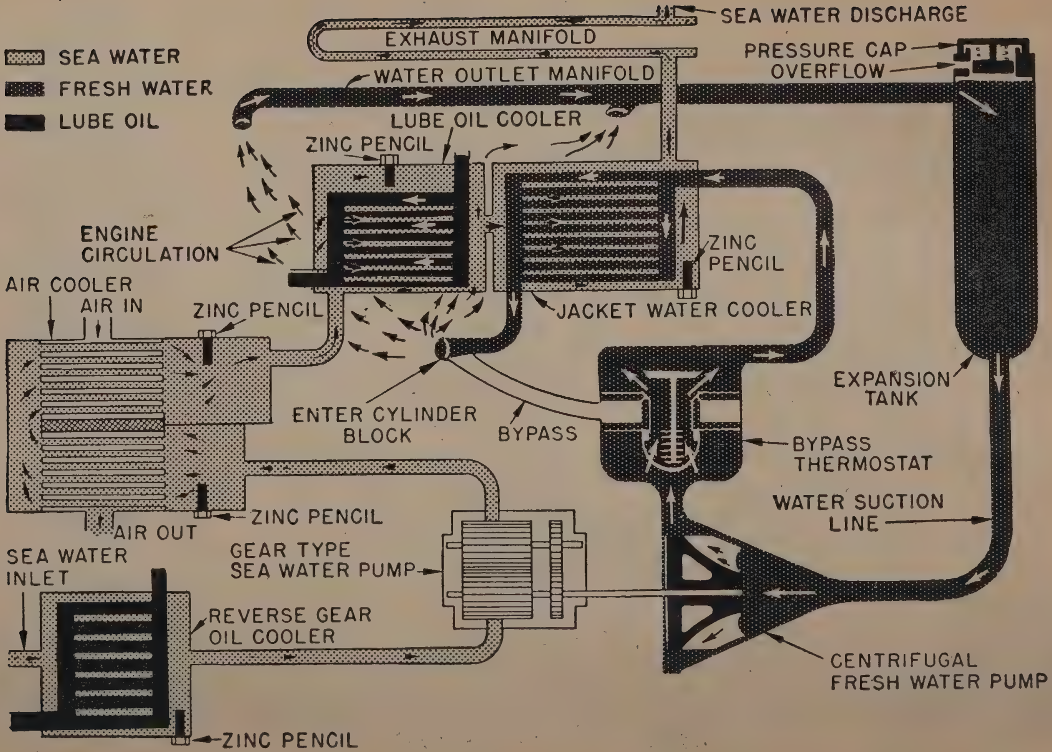


Figure 10-12.—Cooling system diagram.

of operation of all of them is the same. The oil to be cooled is caused to flow through or around a set of tubes with cooling water on the other side. The hot oil gives up its excess heat to the cooler water across the tube wall.

The air cooler in the diagram (fig. 10–12) consists of a bank of tubes through which the sea water passes and around which the air circulates.

The sea-water pump is usually of the gear type, but in some engines centrifugal pumps are used. These pumps are designed to handle a large volume. In medium and small engines, the pump is driven from the gear train; larger engines have a separate pump drive.

The salt-water circulating system on large engines is relatively simple, since its only function is to cool the fresh water (coolant).

Fresh-Water System

As shown in the illustration of the fresh-water cooling system (fig. 10–12), the system is completely enclosed. The fresh water is circulated continuously, by means of a pump, through the engine jackets and the jacket-water cooler.

The pump draws water from the expansion tank and discharges it to the bypass thermostat. The temperature of the water determines whether the thermostat will send the water through the jacket water cooler or pass it directly to the cylinder block. The thermostat is usually set to start opening at about 160° F. and to open fully at 180° F. For large engines operating at speeds in excess of 500 rpm, the minimum lube oil temperature should be 140°, the maximum 180°; the minimum fresh-water temperature should be 140°, and the maximum 170°. However, many small engines are permitted to operate with fresh-water temperatures up to 200° F.

In figure 10–12 the thermostatic valve is shown fully open; all the fresh water is going through the cooler.

Fresh water enters the cylinder block and passes upward through the jacket spaces into the cylinder heads. The water is returned to the expansion tank by way of the water outlet manifold.

The expansion tank serves as a storage tank in which the fresh water can expand as its temperature rises. A pressure cap permits overflow of any excess water and the escape of air.

The purpose of the TEMPERATURE REGULATOR is to maintain a uniform fresh-water temperature. When the temperature of the water leaving the engine is above the temperature for which the regulator is set, the regulator valve INCREASES the flow through the fresh-water cooler and less water is bypassed directly to the lube oil cooler. When the water temperature is low, the regulator valve DECREASES the flow of water to the fresh-water cooler and more water bypasses directly to the lube oil cooler.

The TEMPERATURE BULB is set into the fresh-water line just ahead of the regulator; and a capillary tube cable is connected between this bulb and the bellows in one end of the regulator. The bellows responds to temperature changes in the water and causes the valves in the regulator to open or close as necessary to control the fresh-water flow.

AIR SYSTEMS

Intake, Exhaust, Scavenging, Supercharging

The air system of a typical high-speed engine is shown in figure 10–13. The arrows show the path of the air from intake to exhaust, in the process of scavenging. The blower draws air through the intake silencer and air screen and discharges it to the air box around the cylinders. When the piston is near the bottom of its stroke, the air intake ports and the exhaust valves are opened so that the air sweeps through the cylinder with a swirling motion and out the exhaust manifold. This helps to clear the cylinder of exhaust gases. The mixture of fresh air and exhaust gases passes to the exhaust silencer, from which it passes overboard.

Intake Silencers and Screens

A Diesel engine uses a great quantity of air, and if a silencer is not used, the rush of air through the intake screen to the blower makes an ear-splitting high-pitched noise.

There are several types of intake silencers in use.

The air screen keeps out any large particles which would damage the blower or cylinder liner.

Blowers

Blowers are necessary on all two-cycle engines to drive the exhaust gases out of the cylinder and, at the same time, furnish an ample quantity of fresh air for burning the fuel when it is injected. In nearly all engines the blower is driven

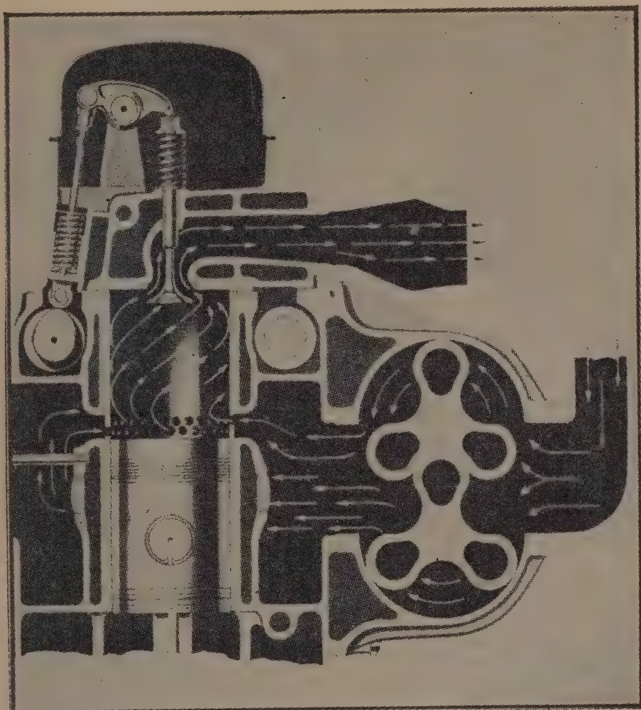


Figure 10–13.—Air intake and exhaust system.

directly by the engine. Generally the blower supplies air at a pressure of 1 to 5 psi.

One of the most efficient types of blower in use is the Roots (or lobe) type. This blower is shown in figure 10–13. Two three-lobed helical metal rotors rotate in opposite directions within the blower housing. The rotors do not drive

each other; in fact, they must not even touch each other or touch the housing. They are accurately machined and timed to keep a very close clearance (1) between rotors, and (2) between rotors and housing. Air which is trapped between the rotor lobes and the housing is carried around and squeezed out by the lobes on the discharge side. Each of the three lobes of each rotor has a helical twist, which helps to provide a uniform and continuous air supply to the engine. The lower rotor is driven by the blower drive gear through an idler gear, and the upper rotor is driven by the lower rotor's gear.

Getting the Air Into the Cylinders

A few four-stroke-cycle Diesel engines have intake valves which open on the piston downstroke; in these engines piston suction draws air in from an intake manifold. The Navy types DA, DB, DC, and DD engines for power boats and Superior engines use this type of air intake.

All two-stroke-cycle engines have an air box around the cylinders; intake air is admitted to the cylinders from the air box by a ring of holes through the cylinder liner (fig. 10–13). A small amount of lubricating oil is blown out into the air box as the compression rings pass the air ports on the power stroke; this oil drains out of the air box through two drilled passages at the ends of the block.

Air Preheaters

When a small Diesel engine is first turned over in cold weather, so much of the heat of compression goes into warming the engine parts that the air temperature does not go high enough for the fuel to ignite. An air preheater is used to heat the air to a sufficiently high temperature. The larger Diesel engines do not require air preheaters.

EXHAUST SILENCERS

The exhaust valves or ports are opened when the cylinder pressure is still as high as 30 to 50 psi. If some means were not taken to muffle the noise it would be almost impossible for a person to remain within operating distance of the

engine; therefore, an exhaust silencer is installed on every engine.

Most exhaust silencers in use at present are of the wet type (shown in fig. 10–13). The silencer consists of a steel drum which is divided into two compartments by a baffle plate. The exhaust inlet pipe extends part way through the inlet compartment so that the exhaust gases must circle back to enter the pipes through the baffle plate. The exhaust gases also pass through a stream of sea water which enters at the top of the silencer. In the outlet compartment, the exhaust gases are again deflected backward before they enter the exhaust and sea-water outlet pipe.

Some engines use a dry type exhaust silencer. It is much like the silencer just described, but without the flow of sea water through the silencer compartments. Instead, dry-type silencers have a water jacket around the compartments.

TURBOCHARGER

A turbocharger is used on some Diesel engines as a means of supplying air for scavenging and for supercharging the cylinders. The exhaust gases from the exhaust manifold drive a gas turbine, which, in turn, drives a centrifugal fresh air blower. The turbocharger has four separate systems:

The EXHAUST SYSTEM consists of an impulse turbine inside a turbine casing. The high-velocity exhaust gases strike the turbine disk and cause it to rotate at high speed. The turbine speed is automatically controlled by the speed and load of the engine.

The AIR INTAKE SYSTEM consists of a centrifugal blower-impeller and an air intake silencer. The blower is mounted on the same shaft with the turbine disk. The fresh air is discharged to the intake manifold.

The COOLING SYSTEM is connected to the main-engine fresh-water cooling system. Fresh water circulates through jackets around the turbine casing and the back plate. The water cools the turbine casing which is in constant contact with the hot exhaust gases. It also cools the back plate, and prevents heat conduction to the fresh air side of the turbocharger.

The LUBRICATING SYSTEM has an oil pump which is driven by reduction gears from the rotor shaft of the turbocharger. The pump draws oil from the sump tank and discharges it, through a filter, to all moving parts of the rotating assembly.

TIMING

Engine timing is largely a matter of opening and closing valves or ports for intake and exhaust. (The timing diagrams shown in figures 10–14, 10–15, and 10–16 also show fuel injection and the compression and power strokes.)

A glance at the timing diagrams will show you that each

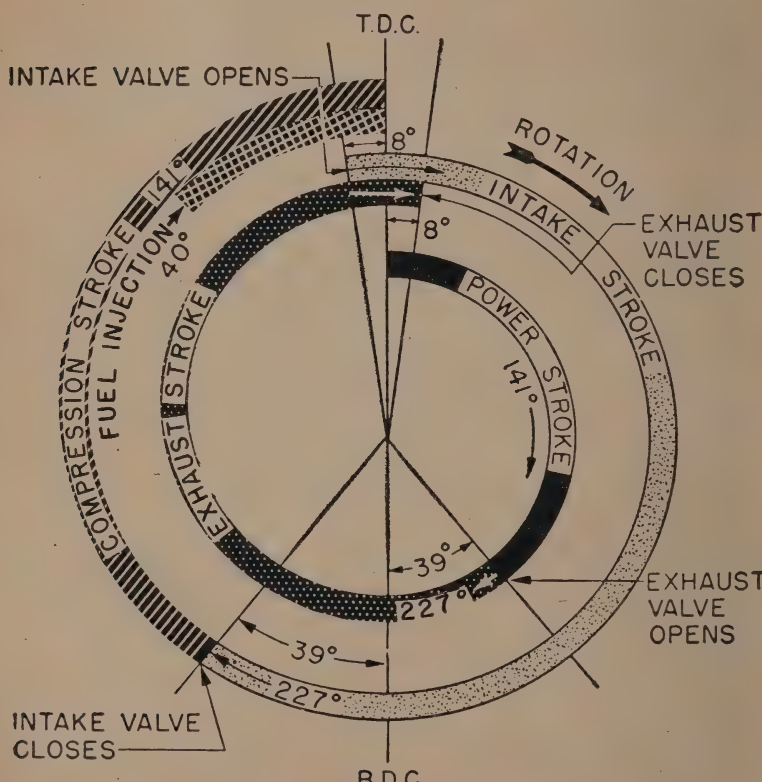


Figure 10–14.—Timing diagram of a four-stroke-cycle engine, not supercharged.

is a circular pattern which represents the amount of crankshaft rotation in a single power cycle. The events in the power cycle are shown in terms of number of degrees of rotation. (The crankshaft rotates 360° in each complete revolution.)

Four-Stroke-Cycle Engine, Not Supercharged

Starting at top dead center (T. D. C.) with the beginning of the power stroke, compression is at its peak, fuel injection has been completed, and combustion is taking place. Power is delivered to the crankshaft as the piston is driven downward by the expanding gases in the cylinder. At 141° after T. D. C. the exhaust valve opens and the exhaust gases blow out through the exhaust manifold; power delivery ends when the exhaust valve opens. The piston continues downward to bottom dead center (B. D. C.) and is then brought upward, in the exhaust stroke. The exhaust gases are pushed out of the cylinder as the piston rises to T. D. C., and the exhaust valve closes 8° after T. D. C. (The crankshaft has made one complete revolution during the power and exhaust strokes.)

The intake valves open at 8° before T. D. C., near the end of the upward (exhaust) stroke. As the crankshaft continues to rotate past T. D. C., the intake stroke begins, and continues for the whole downward stroke, with fresh air being drawn into the cylinder. When the crankshaft has rotated 39° past B. D. C., the intake valves close, and the charge of fresh air is trapped in the cylinder space.

The piston continues upward in the compression stroke which lasts 141° and ends at T. D. C. About 40° before T. D. C. fuel injection begins and continues to T. D. C. However, the actual length of the injection period depends on the engine speed and load. In any case, at T. D. C., after compression, the fuel has been injected into the hot, compressed air in the cylinder, and combustion has begun. The crankshaft has now made its second complete revolution, and the piston is ready to start the cycle again with the next power stroke.

Four-Stroke-Cycle Engine, Supercharged

The supercharged four-stroke-cycle diagram (fig. 10–15) differs from the uncharged four-cycle diagram in several ways. The intake and exhaust valves are open much longer in the supercharged engine and the compression and power strokes are slightly shorter in duration. These changes make possible a long scavenging period in which the intake and exhaust valves are both open. The turbocharger blower fills the cylinder with fresh air under pressure before com-

Figure 10–15.—Timing diagram of a four-stroke-cycle engine, supercharged.

pression begins; in other words, the turbocharger supercharges the cylinder.

Two-Stroke-Cycle Engine

The timing diagram in figure 10–16 shows the timing of a two-stroke-cycle engine. The cycle is completed in one revolution.

Every two-stroke-cycle engine must use a blower to send fresh air into the cylinder and to clear out the exhaust gases. Intake and exhaust functions are accomplished while the piston is in the lower part of the cylinder.

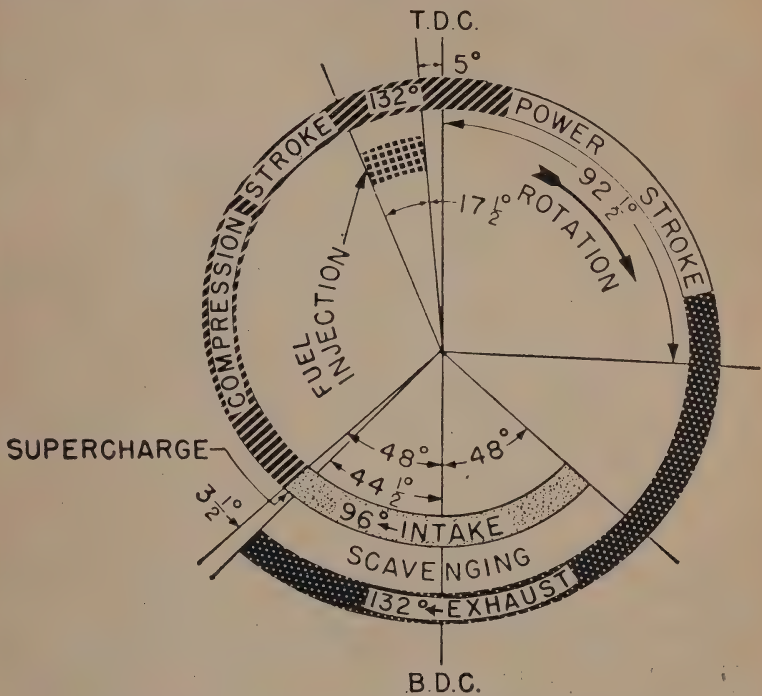


Figure 10–16.—Timing diagram of a two-stroke-cycle engine.

GOVERNORS

The function of a governor is essentially to control the speed of an engine under varying load conditions. The type

of load and the degree of control desired determine the kind of governor to be used. Governors for Diesel engines may be classified as follows:

1. CONSTANT-SPEED GOVERNORS are used to maintain the SAME ENGINE SPEED from no load to full load.
2. VARIABLE-SPEED GOVERNORS are used to maintain ANY DESIRED ENGINE SPEED from idle to top speed.
3. SPEED-LIMITING GOVERNORS are used to control the MINIMUM ENGINE SPEED and to limit its MAXIMUM SPEED, or to limit the maximum speed only.
4. LOAD-LIMITING GOVERNORS are used to LIMIT THE LOAD which the engine will take at various speeds.

Practically all governors used on Diesel engines in the Navy are of the type in which the centrifugal force of a rotating weight is balanced by a helical coil spring. These centrifugal governors may be classified into two main types depending upon the regulating force employed to operate the fuel control. These types are:

1. MECHANICAL GOVERNORS, in which the centrifugal force of the rotating weights DIRECTLY regulates the fuel supply by means of a mechanical linkage.
2. HYDRAULIC GOVERNORS, in which the centrifugal force of the rotating weights regulates the fuel supply INDIRECTLY by moving a hydraulic pilot valve controlling oil under pressure.

Mechanical Governor

The action of a spring-loaded governor is shown in figure 10–17. Two rotating weights are fastened to levers mounted on pivots. The yoke is connected by gears to revolve with the engine. The inner ends of the flywheel levers bear against the thrust bearing of the control sleeve which operates the fuel-regulating mechanism. The speeder spring, often referred to as the governor spring, bears against the upper end of the control sleeve and tends to move it downward: The centrifugal force acting outward on the flyweights has a tendency to move the control sleeve upward against the action

of the spring. When the centrifugal force of the rotating flyweights is exactly balanced by the force of the spring, the control sleeve assumes a fixed position, the fuel-regulating mechanism remains at a predetermined setting, and the engine speed remains constant.

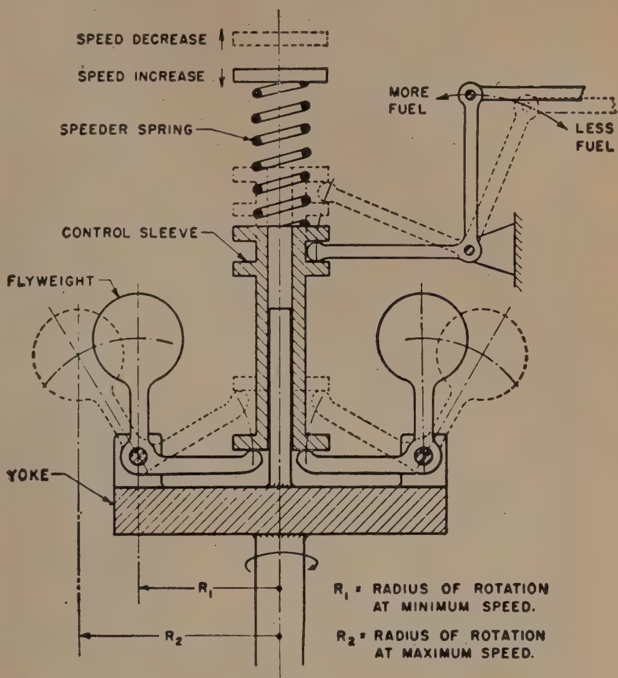


Figure 10–17.—Elementary spring-loaded centrifugal governor.

The simplest method of obtaining variable-speed governing with spring-loaded centrifugal governors is to provide a means for varying the initial compression of the speeder spring, as shown in figure 10–17. Thus, if the initial spring force is INCREASED by compressing the spring to a shorter length, a greater engine speed must be attained before the centrifugal force developed by the flyweights will balance the spring force; and vice versa.

When it is desirable that the governor control the engine so that it idles at low speeds under no-load conditions, it

is necessary to provide two different springs. One is a soft spring to provide better sensitivity at low speeds; the other is a stiff spring to provide sufficient stability at high speeds. For low-speed operation, the governor control is put in a position in which only the soft inner spring is acting. For high-speed operation, the governor control is put in a position in which both springs must act together; this provides better control under full-speed conditions.

Hydraulic Governor

The speed-sensitive element in the hydraulic governor consists of a pair of flyweights and a helical coil spring. This element operates a pilot valve which controls the flow of oil to and from a hydraulic power piston.

AT NORMAL SPEED, the lower end of the plunger just closes the lower port in the pilot-valve cylinder and there is no flow of oil. WHEN THE SPEED RISES ABOVE NORMAL, the valve plunger moves up and opens the port from the power piston, resulting in the oil drawing into the sump. The spring on the power piston forces the power piston down toward a no-load position. The fuel-control mechanism is connected to the power-piston rod end. WHEN THE SPEED DECREASES BELOW THE NORMAL CONTROL SPEED, the flyweights move in, lowering the pilot-valve plunger; this opens the port of the power piston to a supply of oil under pressure. The oil forces the power piston up toward a full-load position. (See fig. 10–18.)

Load-Limit Governors

There is a maximum load which an engine can carry without damage. A speed governor is sensitive only to speed. If the engine slows down, the governor will increase the fuel supply even though this may result in overloading the engine. To prevent overloading the engine, the governor may be equipped with a maximum-fuel stop.

A typical load-limit governor is illustrated in figure 10–19. It consists of a governor which operates a hydraulic pilot

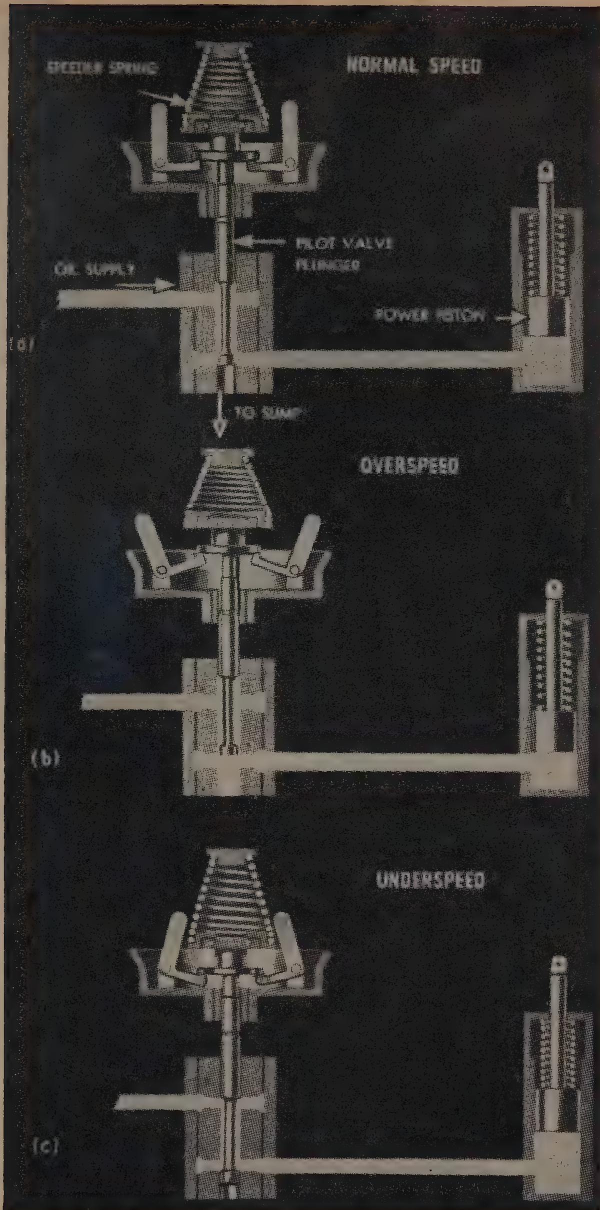


Figure 10–18.—Elementary hydraulic governor.

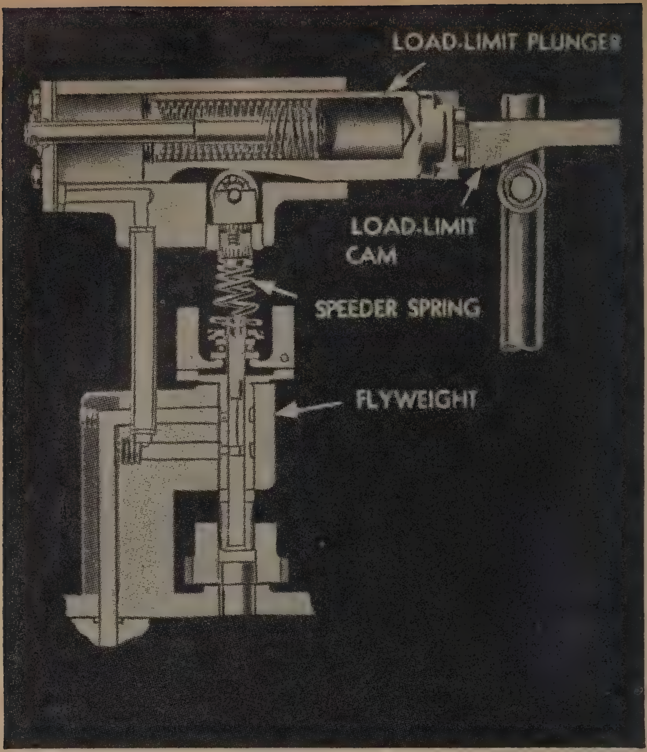


Figure 10–19.—Load-limit hydraulic governor.

valve for controlling the load-limiting mechanism. This mechanism consists of a spring-loaded plunger or piston to the right end of which is attached a stop, or cam, which limits the movement of the main fuel controls. There is a sloping cam surface cut into the lower side of the piston on which rides the roller attached to the top of the speeder-spring. The position of the load-limit piston thus controls the compression on the speeder spring. In operation, WHEN THE SPEED INCREASES the centrifugal force of the flyweights moves the pilot-valve plunger up and uncovers the control port, permitting oil in the load-limit cylinder to drain out and allowing the spring-loaded piston to move to the left; this moves the load-limit stop to the position which permits

maximum opening of the fuel controls. WHEN THE ENGINE SLOWS DOWN, the pilot-valve plunger moves down and opens the control port so that it connects with the supply of oil under pressure. The oil acting on the load-limit piston will move it to the right until the control port is again covered; as the load-limit piston moves to the right, the roller riding on the piston cam surface will move up to reduce the speeder-spring compression, so that the centrifugal force of the fly-weights will be balanced at a lower speed.

Overspeed Governors and Trips

Overspeed governors and trips depend upon spring-loaded centrifugal-governor elements for their action. When the engine speed rises above the desired maximum, the centrifugal force overcomes the spring force and puts into action the controls which cut off or limit the air or fuel supply.

An overspeed control which brings an engine to a full stop is called an OVERSPEED TRIP. If the overspeed control slows the engine down, but allows it to continue to run at safe operating speeds, it is termed an OVERSPEED GOVERNOR.

In an overspeed trip, the shut-off control may be operated by the force of a power spring which is put under tension when the trip is manually reset, and is held there by means of a latch. When its desired maximum speed limit is exceeded, a spring-loaded centrifugal flyweight will move out and trip the latch, allowing the power spring to operate the shut-off control.

STARTING AND REVERSING REQUIREMENTS

The starting speed of a Diesel engine depends upon the type and size of the engine, its condition, and the temperature of the surrounding air.

One requirement in starting a Diesel engine is to turn it over with sufficient speed. If the engine is turned over very slowly, the unavoidable small leaks past the piston rings and through the intake and exhaust valves will permit part of the air to escape during the compression stroke; this may lower

the temperature at the end of the stroke below the ignition point of the injected fuel. The heat loss from the compressed air to the metal walls of the compression space is also greater at low speeds.

Electric System

Electric starting systems use direct current because chemical energy can be stored in batteries and drawn upon as electrical energy when needed.

The electric starting system consists of:

1. Storage battery.
2. Direct-current electric motor.
3. Mechanical engagement between the motor and engine crankshaft.
4. An auxiliary electric generator to charge the battery (if the engine does not drive a d-c generator as its main load).
5. Necessary cables, wires, and switches to complete the electrical system.

Diesel engines use from 12- to 32-volt storage batteries for starting, depending on the type and size of the engine. The capacity and size of the batteries vary with different installations.

The starting motors are usually of the series-wound heavy-duty type, which, for a few seconds, can carry a 100-percent overload.

The mechanical engagement mechanism for a Diesel starting-motor is similar to that used in automobiles.

Compressed-Air Starting

Compressed air, stored in tanks, is used as a source of starting energy when it is allowed to expand in the engine cylinders of large Diesel engines. This use of compressed air requires a starting-valve gear; however, this adds but little extra weight and size to the engine.

With most air-starting systems, the compressed air is admitted to the top of the main engine cylinder under a

pressure of from 100 to 400 psi. The starting valves are timed to open when the pistons are in the position corresponding to the start of the normal compression stroke. The air pressure acting on the pistons turns the engine as rapidly as necessary for starting. When the engine is turning fast enough, the fuel begins to ignite as it is injected; the compressed air supply is then cut off.

Reversing

Small Diesel engines used for boat propulsion are usually connected to the propeller shaft by means of reverse gears. These gears are used to reverse the direction of rotation of the propeller shaft, without changing the direction of rotation of the Diesel engine.

Large Diesel engines used for ship propulsion, when driving the propeller mechanically, must be provided with some system of direct reversing for astern operation. The reversing mechanism must be capable of quickly slowing down the engine to a complete stop and then starting it up in the opposite direction. Furthermore, this must be accomplished against the action of the propeller, which is turned by the forward motion of the ship through the water.

The only satisfactory method for reversing direct-connected Diesel propulsion engines is the use of compressed air in conjunction with the air-starting system. This is accomplished by changing the timing of the air-starting valves so that the compressed air admitted to the cylinders opposes the original direction of rotation. At the same time, the timing of the fuel injection and the intake and exhaust valves is changed to correspond with the new direction of rotation. Thus, as soon as the crankshaft rotation is reversed, the engine will start and operate in the opposite direction.

When the direction of rotation of the crankshaft is reversed, all engine-driven pumps must also be operated in the opposite direction. Geared pumps are provided with automatic-reversing check valves, which, by the pressure of the fluid delivered by the pump, keep the discharge piping con-

nected with the discharge side of the pump. Positive displacement blowers have either a similar arrangement or change-over valves which are operated mechanically. Centrifugal pumps for these engines usually are built with straight vanes; in this type of pump the amount of fluid delivered is not affected by the direction of rotation of the pump.

There are several methods used to change the valve timing and the sequence of valve operation. In a four-cycle engine this is achieved by using a second set of cams so that the valves can be operated in either direction of engine rotation. Ahead and astern cams for each valve are provided side by side on the camshaft. There are two general methods used to bring the second set of cams into position: (1) by sliding the camshaft endwise, and (2) by shifting the cam followers.

When the camshafts are GEAR-DRIVEN from the crankshaft, they may be rotated with respect to the drive gear by means of sliding helical gears or splines. When the camshafts are CHAIN-DRIVEN, the timing of the camshaft with respect to the crankshaft is changed by movable idler sprockets which shorten the effective chain on one side of the drive sprocket while lengthening it on the other side.

CLUTCHES

A device to connect two shafts so that they will act as one is called a COUPLING. A part to connect or disconnect, at will, a part that transmits power to or from a rotating shaft is called a CLUTCH. If two shafts must be connected or disconnected while in operation, the device to be used has the features both of a coupling and a clutch but is commonly called a clutch.

The types of clutches used with Navy Diesel engines are:

1. Friction.
2. Pneumatic.
3. Fluid or hydraulic.
4. Electromagnetic.

QUIZ

1. In general, what is the basis of the Diesel engine classification system used by the Navy?
2. What is the number of power strokes in one cycle of a four-stroke engine?
3. What function is served by the main stationary parts of a Diesel engine?
4. What term is used to indicate the diameter of a cylinder?
5. The main moving parts of a Diesel engine have what kind of motion?
6. What are the main requirements of a Diesel engine crankshaft?
7. What is a major advantage of using cast-iron rather than aluminum for pistons?
8. What term is used to describe those parts which control the admission of air, the discharge of exhaust gases, the admission of fuel, and the admission of compressed air?
9. In a four-stroke engine, what is the speed of rotation of the camshaft?
10. What type of valves are used for exhaust, intake, air-starting, and fuel injection?
11. When the engine heats up, the expansion of the valve stem tends to hold the valves off their seats. What method is commonly used to control this condition?
12. What are the three main types of solid fuel injection systems?
13. Why is the common-rail system of fuel injection not suitable for high-speed small-bore engines?
14. What is a unit injector?
15. What are the principal parts of the Diesel engine lubricating oil system?
16. What is most frequently used as a coolant for naval Diesel engines?
17. What purpose is served by the helical twist of the lobes of a Root-type blower?
18. Why does a small Diesel engine require an air preheater?
19. What kind of exhaust silencers are now most commonly used?
20. Why is a turbocharger used on some Diesel engines?
21. What is the general principle upon which nearly all Navy Diesel engine governors operate?
22. What is the simplest method of obtaining variable-speed governing with a spring-loaded centrifugal governor?

23. What is the name of the overspeed control which brings an engine to a full stop?
24. What two systems are used for starting Diesel engines?
25. How is reversing usually accomplished in small Diesel engines used for boat propulsion?
26. What is the only satisfactory method for reversing large direct-connected Diesel propulsion engines?

CHAPTER 11

BALANCING MACHINES AND PROCEDURES

FUNDAMENTALS OF BALANCING

In the mechanical sense, a body is in balance when its weight is so distributed that the body (for example, a shaft or a pulley mounted on a balanced shaft) will remain in any position in which it may be placed on a pair of knifeways; this is known as static, or standing, balance. Further, weight must be so distributed that there will be no vibration when the body is put into rotary motion; this is known as dynamic, or running, balance. This chapter is concerned chiefly with balancing as a process whereby the distribution of mass in a rotary part of a machine is altered to eliminate vibration at the supporting bearings.

One of the characteristics of modern naval machinery is high rotating speeds. In the design of complex machinery, with high rotating speeds, careful consideration must be given to the proper balancing of rotating parts. This ensures less vibration and noise, greater operating efficiency, and longer bearing and machine life.

Naval main propulsion machinery rotating parts such as turbine rotors, reduction gears, Diesel engine crankshafts, and ships' propellers are accurately balanced before they are assembled or installed. The Machinery Repairman will be more concerned with the rotating parts of auxiliary machinery. In making repairs and installing replacement

parts he will have to check or properly balance these parts before the job is fully completed. Some of these items of repair that will require balancing are various pump rotors, including impellers; auxiliary turbine rotors; blower and ventilation fans; and various shafts with attached gears or assemblies. From the electric shop, the Machinery Repairman will receive motor and generator armatures or rotors. Armatures that have been rewound will require balancing in order to ensure excellent service.

With a good understanding of the principles involved in regard to balanced parts, a Machinery Repairman supervising repair work will be careful to see that nothing is done that will disturb balanced machinery parts. He must see that such parts are not dropped, sprung, or bent. He must also see that great care is taken in the interchanging or removal of counterweights, and in the addition or removal of material at any point that will affect balance. He will know when necessary repairs will disturb the balance so that the part or assembly will require rebalancing. He should never attempt the straightening or repairing of bent or sprung shafts when new ones can be made or obtained.

UNBALANCE

Causes of Unbalance

Some of the causes of unbalance in rotating machinery parts or assemblies can be easily detected. There are others that cannot be readily detected. The following paragraphs suggest some of the factors that introduce unbalance effects.

1. Damage to Parts or Assemblies.—Shafts that are parts of an assembly which may include impellers, fans, gears, turbine wheels, electrical armatures, etc., will cause unbalance when they are bent or sprung out of alignment. A rotating part such as a pump impeller, turbine blading, or fan, if defective, will cause unbalance of the unit. Erosion of a high-speed pump impeller in most cases will not be uniform. Also, small amounts of metal may be broken loose from the impeller blading at one or more places. Fans

of various types are usually damaged by having the blading bent out of shape, and it is difficult to return the blading back to the original balanced condition. Damage to blading of a steam turbine will cause unbalance.

2. Changes Made During Repair Operations.—When damage to a fan or similar piece of machinery is being repaired, care should be taken to replace all the counterweights that have been removed. The counterweights and their locations should be properly marked before removing them, so that the original condition of balance can be restored. When repairs are being made by means of gas or electric welding on balanced machinery parts, the addition of extra metal or weight will cause unbalance. If it is impractical to restore the original dimensions and material, the unit or assembly undergoing repairs must be rebalanced.

An outstanding example of unbalance resulting from repair operations is a rewound electrical motor armature. When an armature is repaired, the coils cannot be rewound so that original balance will be restored. Also, the insulating varnish cannot be applied with precise uniformity. Therefore, all electrical armatures and similar parts must be rebalanced before the repair job can be considered completed.

3. Unmachined Portions of Castings.—A casting such as a pump impeller cannot be considered as being in a balanced condition simply because it may be symmetrical in general appearance. A blade or section of the wheel on one side of the rotational axis may be heavier than a blade or section on the opposite side. Balanced conditions cannot be ensured when castings are made. Also, a rough casting cannot be accurately chucked in a lathe for turning and boring when the center of gravity and balanced conditions are considered.

4. Lack of Homogeneity in Metals.—A completely machined part such as a pulley or gear wheel may appear to be in a balanced condition, but actually be unbalanced because of a blow-hole in the metal inside the wheel. Unbalance may also result from slag inclusions and variations in the crystal-

line structure in the metal used for the manufacture of rotating parts. Except for those appearing on the surface, defects of this nature cannot be detected without special examination. It is a quicker and better procedure to balance the rotating part than to try to determine the homogeneity of the material. There are some items of critical nature, such as handybilly flywheels, where magnaflux tests or other special tests are used to detect small cracks or defects after the wheel has been carefully balanced. But, as a rule, items of this nature are not manufactured or repaired by naval repair activities.

5. Nonsymmetrical Distortion During Operation.—This cause of unbalance may occur in some types of fans or blowers. In the case of squirrel cage fans, for example, the sheet metal blades under load at operating speed may stretch or distort from their position when the blower is standing still or operating at slow speeds. Because of initial stresses and variations in thickness of metal, such distortion may not be uniform throughout the fan and an unbalanced condition may result. If it seems likely that this type of an unbalanced condition may occur, the fan or blower should be checked for proper balance at its normal operating speed.

6. Variations Introduced by Allowable Tolerances.—Tolerances are allowed in the machining of all parts. Plans or blueprints state the tolerances allowed in the manufacture of replacement parts. When parts such as pulleys and gear wheels are machined, the center of the outside diameter may be within tolerance requirements but this will not necessarily mean that it is the center as determined by the rotational axis of the bore. One side of the pulley or gear wheel will be heavier than the other side and however slight the difference will be, it will produce a certain amount of unbalance. The tolerances which permit eccentricity or lack of squareness of machined surfaces with respect to the rotational axis are taken into consideration when designing machine parts. When high-speed rotating parts are being machined, it is necessary not only to see that the measurements are within

the required tolerances, but also to ensure that these parts be carefully balanced.

Manufacturing tolerances permitted for economical assembly of different parts may also be a cause of unbalance. When two or more parts which are in a balanced condition are put together, there is a possibility of the entire unit being unbalanced, because of a small clearance in the flange surface or a loose fit in the assembly joint which will allow a radial shift between the units. This will cause the complete rotating assembly to become unbalanced. An example is a crankshaft and a flywheel. Each by itself may be a balanced unit. But when the two are bolted together a condition of unbalance may be produced if the axis of the flywheel is not in alignment with the axis of the crankshaft. In cases of this type, the entire rotating unit should be balanced after it has been assembled.

Unit of Unbalance

The centrifugal force exerted on the restraining bearings of an unbalanced rotor is proportional to both the weight of the rotor and the distance its mass center is displaced from the rotational axis. Therefore, unbalance is measured as a product of weight and displacement in terms of ounce-inches. An unbalance of 1 ounce-inch is produced by a 1-ounce weight displaced 1 inch from the rotational axis.

A rotor weighing 62.5 pounds (1,000 ounces), the mass center of which is 0.001 inch from the rotational center as determined by its bearings, is 1 ounce-inch out of balance. The product of the weight (1,000 ounces) and the displacement of the mass center (0.001 inch) is equal to 1.0 ounce-inch; or, 1,000 ounces times 0.001 inch = 1.0 ounce-inch.

Force Exerted by Unbalance

The magnitude of the centrifugal force produced by an unbalance of 1 ounce-inch is a function of the speed of rotation. This force, which produces vibration, increases as the square of the ratio of increase of the rotational speed.

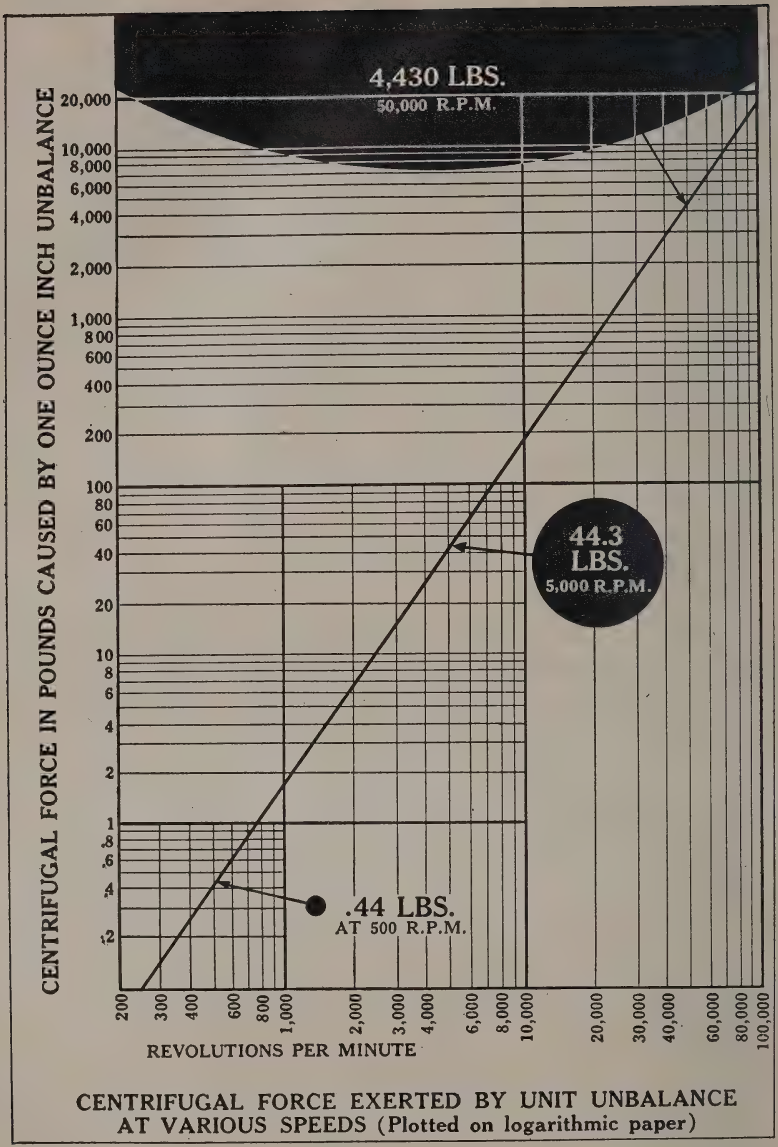


Figure 11–1.—Centrifugal force exerted by unit unbalance at various speeds

Note, in figure 11–1, that 1 ounce-inch of unbalance at 500 rpm produces 0.443 pound of centrifugal force, and that at 5,000 rpm (a speed ten times greater) centrifugal force has increased to 44.3 pounds (centrifugal force one hundred times greater). At 50,000 rpm, a common enough speed in some types of machines today, the centrifugal force due to an unbalance of 1 ounce-inch is now 4,430 pounds—a force of over 2 tons.

It is obvious that there is a much greater need for accuracy of balance at higher speeds than there is at lower speeds. The degree of balance required in a particular case can be determined only after a consideration of operating speeds and the conditions under which the rotating part operates.

TYPES OF BALANCING OPERATIONS

Balancing operations are of two types, static or dynamic. Static balancing requires only the application of a single correction weight to the rotor. In dynamic balancing, two correction weights are needed, each in proper position and each in a separate plane; these planes must be spaced some distance apart and perpendicular to the rotational axis.

Static Balancing

Static balancing is the term applied to the procedure of balancing the mass of a rotating part when it is rotating so slowly that it will not be affected by centrifugal force. Static unbalance, when of sufficient magnitude, can be observed when the unbalanced part is placed on a pair of horizontal knife edges as shown in figure 11–2.

There are several methods of testing the static balance of a rotating part. For the purpose of illustration we will use the method as shown in figure 11–2. If the wheel is unbalanced, it will roll until the heavy side is downward, with the unbalanced point in the lowermost position.

If the disk of figures 11–2 and 11–3 is unbalanced only by the 5-ounce weight W which is 2 inches from the rotational axis O, the amount of unbalance is 5 times 2, or 10 ounce-inches. This unbalance of 10 ounce-inches may be

corrected by a weight of known value placed opposite the heavy point and at such a distance from the axis that the product of weight and distance will also equal 10 ounce-inches. Thus, the weight C of 2.5 ounces placed 4 inches from O will correct the unbalance caused by W. The 10 ounce-inches of centrifugal force exerted by W is opposed by the 10 ounce-inches of correction weight C, and the disk is in perfect static balance.

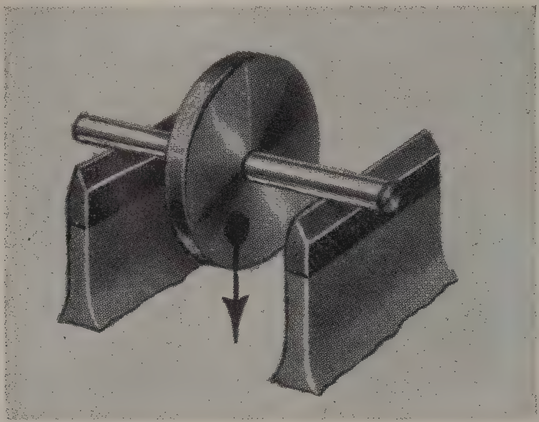


Figure 11–2.—A simple method of static balancing.

This procedure of balancing consumes an excessive amount of time due to the fact it is basically a method of trial and error. More advanced methods, such as the use of balancing machines, are now used to check or obtain the static balance of a rotating part. The static balancing of a rotating part by the trial and error method described is practicable only in the case of a rotating part with large diameter and relatively short axis—such as the disk or wheel indicated in figure 11–2. When the rotating part has a relatively long axial length, other factors are introduced which make dynamic balancing necessary.

Dynamic Balancing

The presence of dynamic unbalance—or moment unbalance, as it is sometimes called—does not become apparent

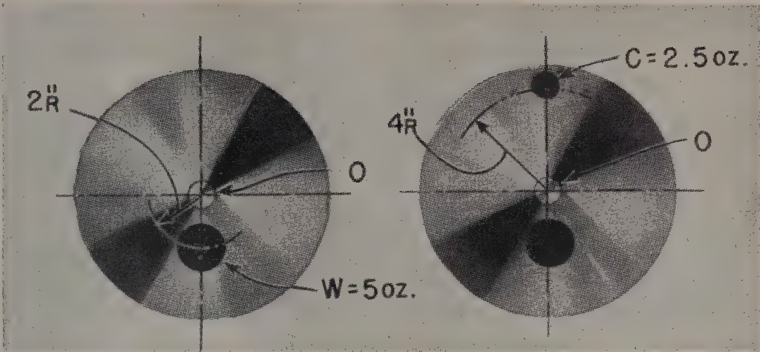


Figure 11–3.—Correcting an unbalanced condition.

until the part in question is rotating. This type of unbalance is caused by two weights so located that, unless the part is restrained in bearings, equal and opposite centrifugal forces are produced when the part rotates. (See fig. 11–4.) When the part is at rest, the products of the weights and their respective distances from the rotational axis have the

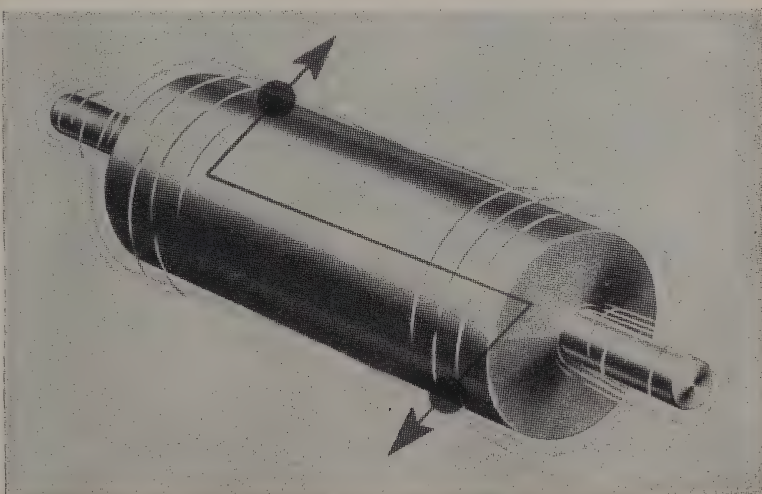


Figure 11–4.—A rotating part with relatively long axis.

same value, and the part is in perfect static balance; but as soon as the part begins to rotate, the centrifugal forces which these weights produce will make the cylinder ends tend to move in opposite directions.

This dynamic unbalance can be corrected by applying two additional weights spaced some distance apart, and each in a separate plane perpendicular to the rotational axis. Look again at figure 11–3, where the correction weight has been added so as to bring the disk into static balance. Suppose now the thickness of this disk is increased until it becomes a cylinder, as illustrated in figure 11–5. With correction weight C applied at a point diametrically opposite from W, the cylinder is in balance while it remains at rest; but once it begins rotating, the two weights produce opposite centrifugal forces (in this case unequal as well as opposite), and the part is in dynamic unbalance.

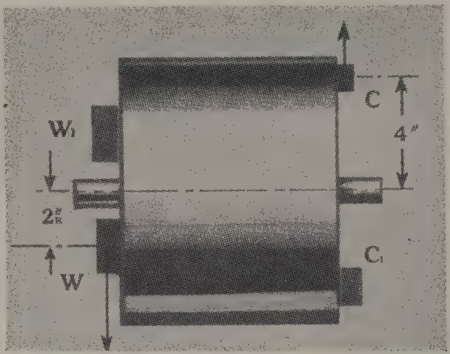


Figure 11–5.—The addition of counterweights to obtain dynamic balance.

Even if these weights were identical, and at an equal distance from the rotational axis (see fig. 11–4), the part would be in dynamic unbalance, because at any given instant the centrifugal forces, though equal, would cause the cylinder ends to move in opposite directions.

If two additional weights, W_1 and C_1, are applied as indicated, they will introduce a total moment force (product of weight times moment arm) that will be equal and opposite

to the combined moment force of the original weights W and C. The part will then be not only in static but also in dynamic balance; this has been accomplished, in effect, by the addition of weight in each of two planes spaced some distance apart and perpendicular to the rotational axis.

Combined Static and Dynamic Balancing

Ordinarily, rotating parts will have both static and dynamic unbalance. This is illustrated in figure 11–6—the two equal weights near the ends cause dynamic unbalance, and the introduction of the third weight puts the part into static unbalance also. Such combined static and dynamic unbalance can be corrected by weights placed in two different planes perpendicular to the axis of rotation.

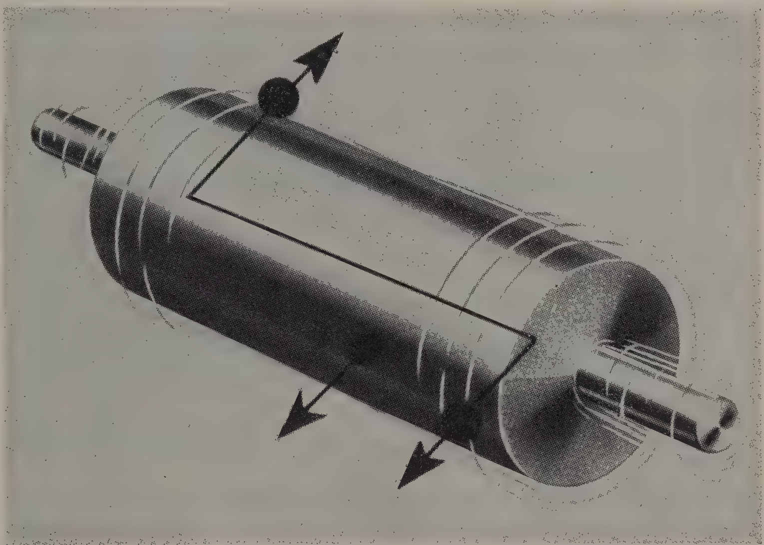


Figure 11–6.—An example of combined static and dynamic unbalance.

Each TRANSVERSE SECTION of the part illustrated in figure 11–6 will be unbalanced. In figure 11–7, let W represent the unbalance in one such section. And let planes L and R be those in which corrective weight can be most conveniently added or removed without affecting desired qualities in the

part. By adding weights in planes L and R, it is possible to neutralize the centrifugal force of W.

In figure 11–7 the heavy spot W happens to be nearer to correction plane L than to R. If the unbalance W of 6 ounce-inches is in the relative position shown, it may be compensated for by the two correction weights C_L of 4 ounce-inches and C_R of 2 ounce-inches. Note that C_L and C_R are of dissimilar sizes and that, while their sum equals W, the larger correction weight C_L is placed in the correction plane nearer to W.

In similar manner, corrections could be made in planes L and R for the unbalances in each of the other transverse sections of the part. Then an effect identical with the resultant effects of all these individual L or R corrections can be produced by a single correction weight. And so, with two corrections of proper size and position, one in each of two planes, the body is corrected for both static and dynamic unbalance.

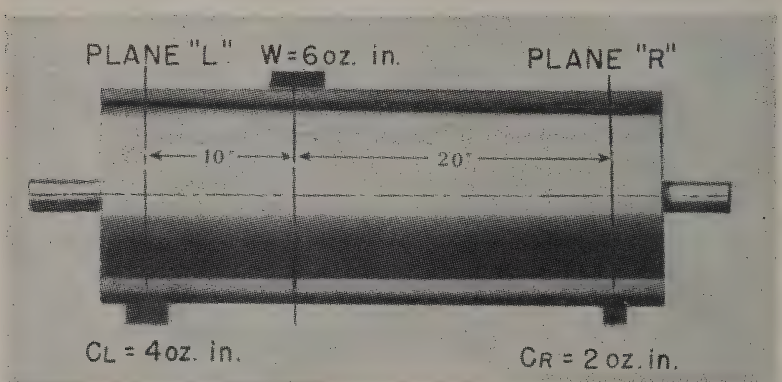


Figure 11–7.—An example of two-plane balancing.

It is this method of two-plane balancing—correcting both static and dynamic unbalance—which is generally called dynamic balancing.

BALANCING MACHINES AND THEIR FUNCTIONS

We have seen that balancing is a process whereby the distribution of mass in a rotating part, or rotor, is altered to

eliminate vibration at the supporting bearings. Under present practice, there are usually two steps to the process; first, the locating and measuring of the corrections required, and second, the application of such corrections.

For the correcting of dynamic unbalance, we depend largely upon the balancing machine. It is the function of such machines to give exact and understandable information on how large corrections should be and where they should be placed. And this information—the amount and angular location for corrections in each of two planes which are perpendicular to the rotational axis—should be in terms readily understood by the operator.

Some of the prime requisites of a good balancing machine are discussed below.

Separation of Unbalance Effects into Two Correction Planes

As has been stressed above, the correction for dynamic unbalance must be made in two planes perpendicular to the axis and spaced some distance apart.

One requisite of a good balancing machine is that it indicate directly the amount and angular location of the correction required in each of the two planes. Selection of these planes should be determined only after consideration of the design and function of the piece, and of where and how corrections can be most quickly and economically applied.

If the balancing machine is to give direct indications of corrections in each of the two selected correction planes it must have certain elements, the need for which may be appreciated by referring to figure 11–8. The cylinder represented here is supposed to be rotating, and to be very flexibly supported at A and B. L and R represent the two selected planes in which corrections can be made and the cylinder has only one unbalance, W, which for the purpose of this discussion is placed in the R correction plane. As the piece rotates, the unbalance W will not only cause pronounced vibration at the B bearing, but will also cause vibration at bearing A. This is the case even though we see that the only

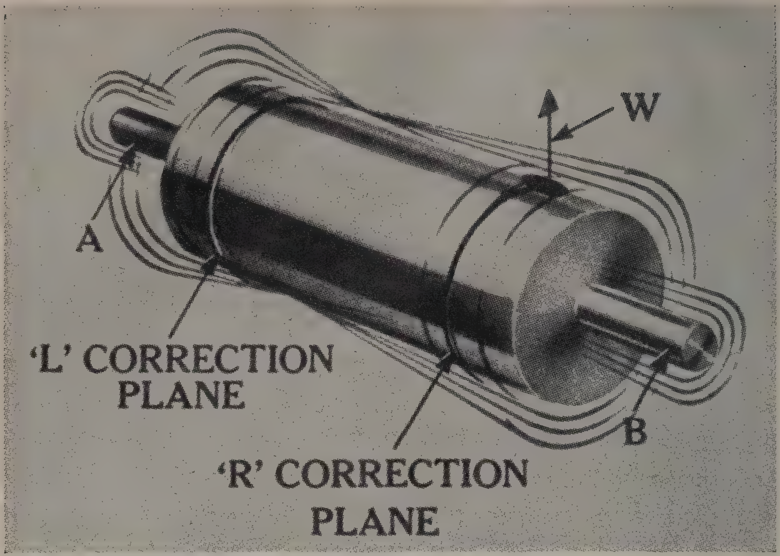


Figure 11–8.—The separation of unbalance effects in each of two selected correction planes.

correction required to balance the piece perfectly will be in the one plane R. We can now see that if unbalance is present in both planes of correction, the motion of bearings A and B are complex, because each bearing is caused to vibrate by the unbalance in both of the correction planes. Unless some means of separation is interposed between the bearings and the ultimate-unbalance indicating device of the balancing machine, it is impossible to get direct indications of unbalance in either plane. The motion of the bearings alone cannot be used as a measure of unbalance, and machines which use only bearing motion for this purpose are trial-and-error or guessing devices.

There are three methods by which this separation of unbalance effects in each of two selected correction planes can be accomplished.

One method, that of employing a PIVOTED CRADLE, was originated about twenty-five years ago. This is shown schematically in figure 11–9. The part to be balanced is supported

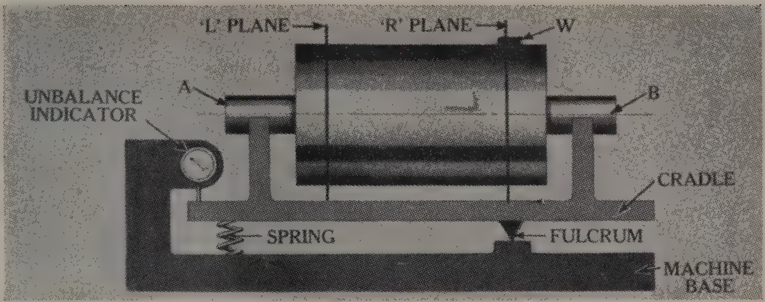


Figure 11–9.—The pivoted cradle.

at A and B on a cradle arranged with a fulcrum which is placed in one or the other of the two selected correction planes L or R while unbalance effects in the other correction plane are measured. The cradle, at a point removed from the fulcrum, is spring-supported; and, as the piece is rotated, unbalance indications for the plane being measured are obtained by noting the amount of motion between the cradle and the machine base at a point away from the fulcrum. Referring again to figure 11–9, the centrifugal force of W in plane R will show a zero reading on the indicator, since the centrifugal force acts on the cradle where it is supported by the rigid fulcrum. When the fulcrum is placed in plane L and the piece is again rotated, only the unbalance W in plane R will show a reading uninfluenced by any unbalance which may be in plane L.

The pivoted cradle provides a means for separating unbalance effects into two selected planes, but, unfortunately, the dampening effect of the unavoidable parasitic mass of the cradle reduces the vibration produced by a given unbalance and so reduces the accuracy of measurement.

Another method, more recent than the pivoted cradle, is shown schematically in figure 11–10. It employs a nodal bar and the cylinder is flexibly supported by bearings at A and B. These bearings are attached to the nodal bar, which will have the same motion as the axis of the cylinder.

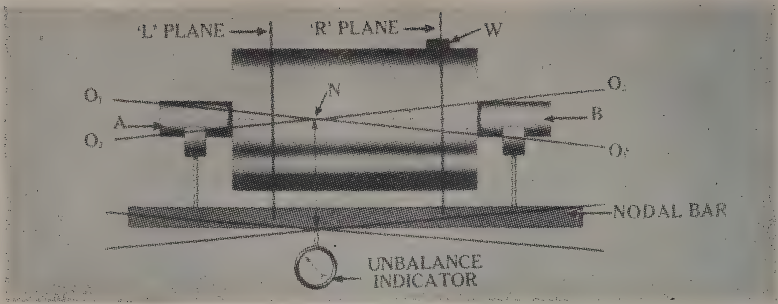


Figure 11–10.—The nodal bar.

Assume for the purpose of this explanation that the cylinder is in perfect balance except for an unbalance W in plane R. As the piece is rotated, the axis will vibrate between lines O_1—O_1 and O_2—O_2, motion at the B bearing being larger than motion at the A bearing. At point N along the axis and at the corresponding point on the nodal bar there is no vibratory motion. This is called the nodal point, and an unbalance indicator placed at this point will give no reading of unbalance W in plane R. It will, however, indicate any unbalance which may be in plane L. It is also possible to locate a second nodal point which will indicate unbalance in plane R uninfluenced by unbalance in plane L.

Here, too, in this method of plane separation, the parasitic mass of the nodal bar and the connecting members reduce the accuracy of measurement. And accurate location of the nodal point is difficult because of the small motion involved.

The third method of plane separation, by electrical networks, is shown schematically in figure 11–11.

Here again the cylinder is flexibly supported on bearings at A and B. Attached by rod to each of the bearings are lightweight coils in the fields of strong permanent magnets. These coils have a motion determined by the displacement of the axis of the cylinder and are connected through an electrical network to a meter which is the unbalance indicator. When the coils vibrate within their respective fields because

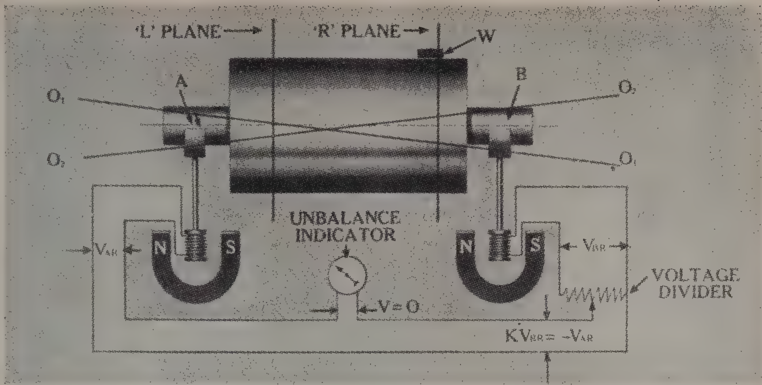


Figure 11–11.—Electrical-network device for locating unbalance.

of the vibration of the bearings to which they are attached, there is generated in the coils an alternating voltage with a magnitude proportional to the amplitude of bearing displacement.

When an unbalance W is introduced in plane R and the piece is rotated, the axis of the cylinder will vibrate between lines O_1—O_1 and O_2—O_2, the direction of motion of the A bearing, at any instant, being opposite to that of the B bearing; likewise, the directions of travel of the two coils are opposite and the generated voltages Var and Vbr are opposite. And each of these voltages is proportional to the displacement of its respective bearing. We see voltage Vbr will be greater than voltage Var because the motion of bearing B is greater than the motion of bearing A.

Now, with the voltage divider, Vbr can be reduced to KVbr, which is equal and opposite to Var, and the unbalance indicator will show a zero reading because we have nulled out the effect of unbalance in plane R. With two such electrical networks, either of which is selected by a simple left-right switch, indications of amount of unbalance are given directly for either the L or R plane, each indication being unaffected by unbalance in the other. This is true plane separation with electrical devices which are free of parasitic mass effects.

Now then, with the network arranged as in figure 11–11, where the effects of any unbalance in plane R have been nulled out, let unbalance W_1 be introduced in plane L as in figure 11–12. This unbalance will cause the axis to vibrate between O_3—O_3 and O_4—O_4 and voltages Val and Vbl will be generated, voltage Val being larger than Vbl because the motion of A bearing is the larger. With the voltage divider

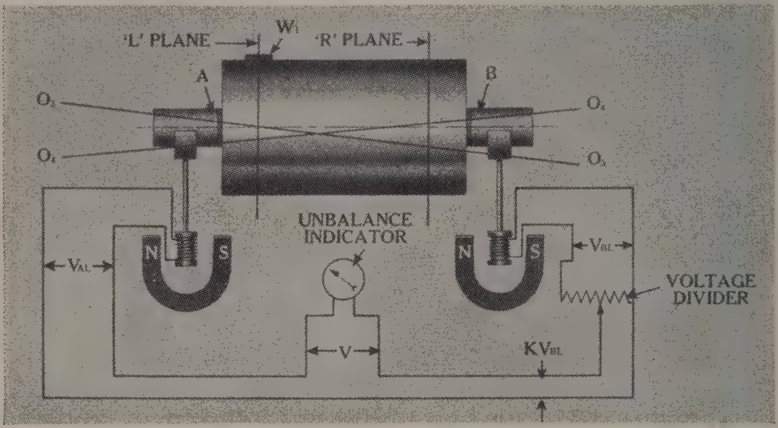


Figure 11–12.—Checking both planes by the electrical-network device.

previously adjusted, as in figure 11–11, to ignore the unbalance in plane R, Vbl is reduced to KVbl which is opposite to Val. Voltage V, the result of KVbl and Val, is shown by the unbalance indicator and is a true measure of the amount of unbalance in plane L.

Mass of Work-Supporting Structures

Since, in any balancing machine, the amount of vibratory motion of the rotating piece is the means whereby the amount of unbalance is determined, the work supports of the machine must be light for maximum vibratory motion due to any given unbalance.

An unbalanced part would have maximum vibratory motion if rotating freely in space. But parts must be supported while in a balancing machine and the mass of the

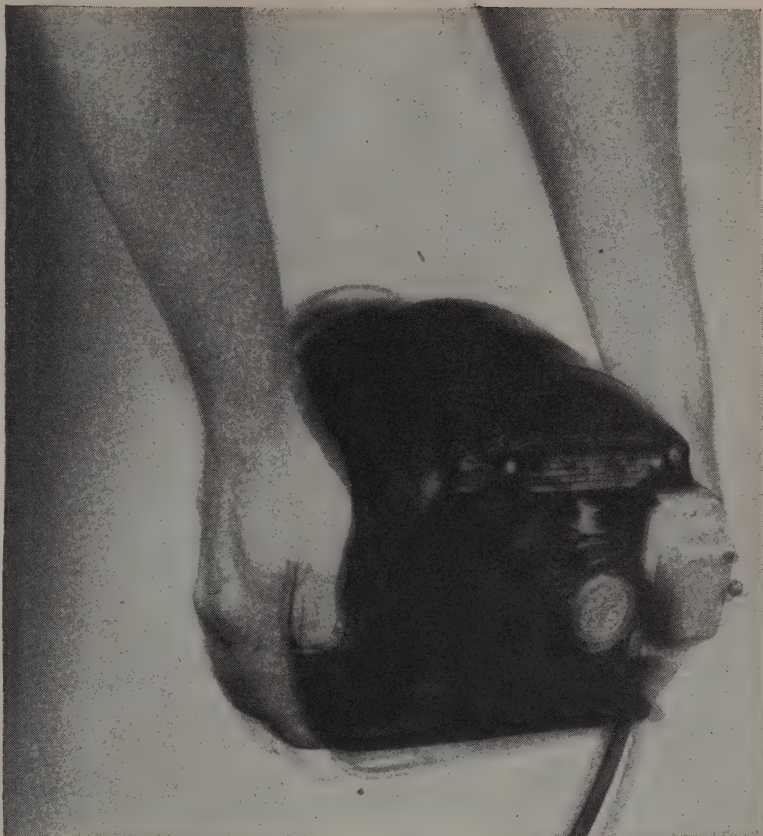


Figure 11–13.—Vibration of an unattached electric motor.

support, in addition to the mass of the piece, must be moved by the forces of unbalance. This added mass of the supports reduces the amplitude of the vibratory motion.

Here is a simple illustration: Vibrations due to unbalance in the small electric motor in figure 11–13 are definitely felt, but in figure 11–14—where the motor is fixed to a block nine times its own mass—the vibration is hardly appreciable. Although in each case the centrifugal forces of unbalance are the same, the amplitude of vibration in figure 11–14 is only $\frac{1}{10}$ of that in figure 11–13, the total mass in

Figure 11–14.—Vibration is decreased when the motor is bolted to a heavy block.

figure 11–14 being ten times greater than in figure 11–13. There is a similar effect when the work-supports of a balancing machine are too heavy.

Because of this, the better balancing machines employ extremely lightweight members for supporting the work-piece. There is negligible reduction of the vibratory motion

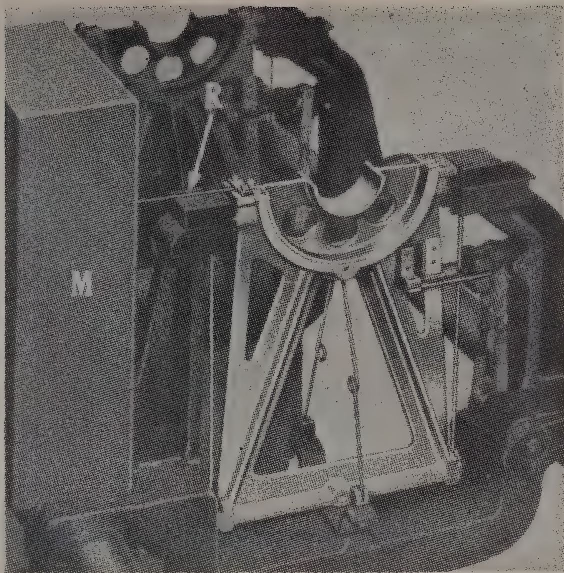


Figure 11–15.—Work-support member of a balancing machine.

of an unbalanced rotating piece. Even for the smaller workpieces the work supports of some machines seldom weigh as much as the minimum piece; and, of course, with larger ones the weight of the support, proportionately, is even less. Each work support is suspended on steel wires or springs offering minimum restraint to the vibratory motion, which is shown in figure 11–15 as being transmitted to a coil within a magnet under cover M through a rod R.

Measurement of Amount of Unbalance

Since the vibratory motion of an unbalanced piece is small, and since measurement of such motion is the only means of determining the size, or amount, of required correction, it follows that some means must be employed to amplify this motion for purposes of precise measurement. Note that we are speaking of amount of corrections and leave for later attention the question of proper angular location of correc-

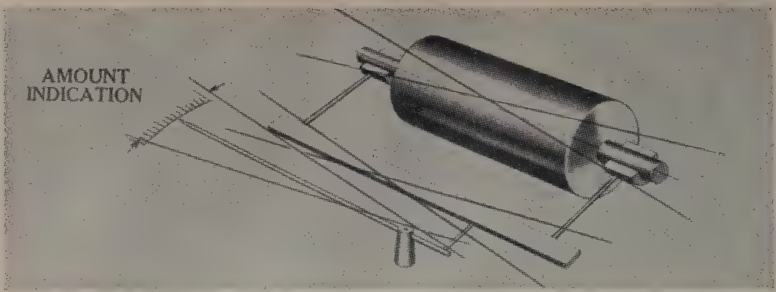


Figure 11–16.—A mechanical method for measurement of unbalance.

tion. Three methods of measurement of amount of unbalance have been used which may be termed mechanical, optical, and electrical.

A mechanical device for the determination of the amount of unbalance is shown schematically in figure 11–16, which indicates how amplification of the vibratory effects of unbalance is effected by single or compound levers, for purposes of more precise reading on a large scale. A standard dial indicator may also be used for this purpose. Because of the inertia of their members these devices can follow only vibrations of low frequency; and at low frequencies, centrifugal forces are so small as to be seriously affected by the friction of the pin joints employed. The unbalance which will produce a force sufficient to overcome such friction represents the minimum unbalance such a device is capable of measuring. And, in this case too, the members of such an amplifying device are a parasitic mass which reduces the amplitude of the vibratory motion.

A method which avoids the inertia and friction difficulties mentioned above is one employing an optical lever, as illustrated in figure 11–17. Here a mirror is connected with the vibratory work support and reflects a beam of concentrated light from a fixed source to a scale on a screen. As the mirror's inclination is changed by the vibratory motion of the work support, the reflected beam on the scale makes a streak of light the length of which is a measure of vibration

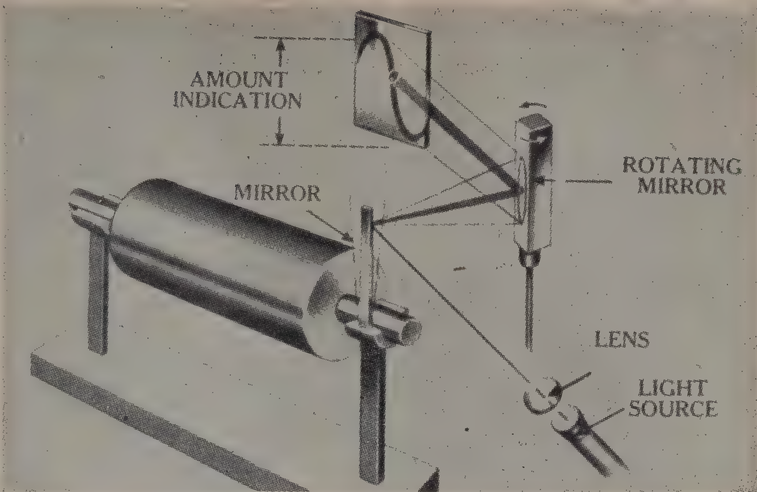


Figure 11–17.—An optical method for measurement of unbalance.

amplitude and of the amount of correction needed. Amplification can be varied by changing the length of the beam between the mirror and the scale. One of the limitations of this device is that as the beam is increased in length for greater amplification, the beam appears on the screen as a spot instead of a point, and the length of the streak of light on the screen becomes too long by one spot diameter. Determination of amount of unbalance then becomes a matter of operator skill in interpreting the streak.

An electrical method of measuring amount of unbalance and the amount of correction required is shown schematically in figure 11–18. In this method there is no lost motion between the vibratory support and the amount indicator.

The output of the electrical network is led into an amplifier before reaching the amount indicator; this amplification can be of any desired order—1,600,000 times or more—and is easily varied to suit particular jobs. The result is a definite stable meter indication large enough for precise reading of the amount of unbalance.

Indication of Place Where Correction Should Be Made

In addition to indicating the amount of correction required in each of the selected planes, a balancing machine must indicate the point on the periphery in each of these selected planes where corrections must be applied to balance the piece—that is to say, the angular locations for corrections must be pointed out. If a precise determination of the amount of the correction is required, it is apparent that determination of the location of such correction must be equally precise before the end result of a balanced piece can be obtained. And it is essential that the accuracy of the means used to determine angular location be independent of the amount of unbalance in the piece so that in the case of small unbalance the indications of location may be exact.

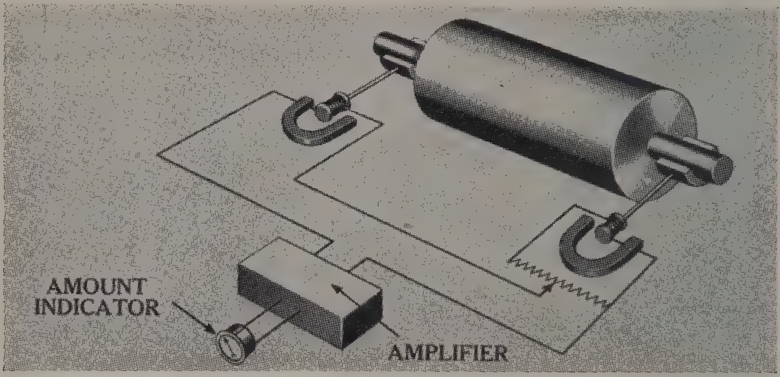


Figure 11–18.—An electrical method for measurement of unbalance.

Electrical-network balancing machines employ electrical devices for indicating the place where corrections should be made. One of these is an electron tube functioning as a stroboscopic lamp. (See fig. 11–19.) This is used when it is practical to rotate the workpiece at a speed of 800 rpm or more.

The stroboscopic lamp is triggered to flash each time the voltage in the electrical network changes from negative to positive. Even the small voltage from the network generated by the minute vibratory effects of the smallest unbalances is

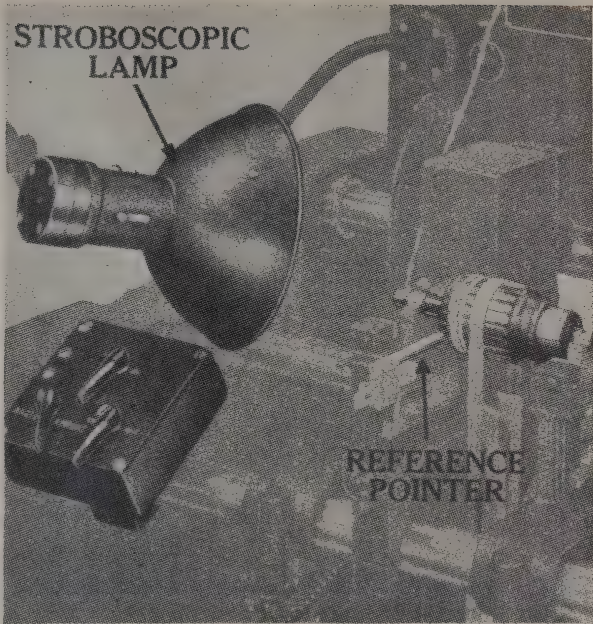


Figure 11–19.—Lamp method for indicating location for correction.

so greatly amplified in this type of a balancing machine that the voltage which actually triggers the lamp has a modified wave, with high definite crests. The stroboscopic lamp is triggered repeatedly at the same point in the rotation of the workpiece whether the unbalance present be large or small. The amplified triggering voltage for the lamp is more than 15 times the voltage supplied to the amount of unbalance meter. Indications of the locations for correction are shown with an order of accuracy greater than that for indication of amount. The same stroboscopic lamp, reference pointer, and angle band on the piece are used for location in each of the two correction planes.

Under conditions of continuous use and when the workpiece is rotated at less than 800 rpm, stroboscopic flashing becomes noticeable as such and tends to cause operator eyestrain; at higher speeds, it appears as an uninterrupted illumination.

Another method for determining angular locations for corrections uses a wattmeter which measures the average value of the product of an instantaneous voltage and an instantaneous current—that is, it measures the average power. The instantaneous voltage used is the amplified output of the network; the instantaneous current is supplied either by a sine-wave generator coupled to the end of the workpiece, or by the amplified output of a photoelectric tube actuated by a reference spot of contrasting color on the workpiece.

With the wattmeter method the operator, by turning a handwheel or knob, brings the pointer of the wattmeter to a reading of zero. Associated with the handwheel or knob, there is an indicating device that will point to the angular location at which corrections are made.

Elimination of Unwanted Vibrations

In all balancing machines the piece is supported in a flexible structure which offers minimum restraint to the vibratory motion produced by unbalance. This structure, with associated amplification devices, is sensitive to vibrations produced by other means as well as to those produced by unbalance; and unless the characteristics of such flexible structures are understood so they may be properly employed, a balancing machine may very well amplify and measure as unbalance those vibrations transmitted through a common floor from machinery such as punch presses and lathes under intermittent cut.

The characteristics of the flexible work-supporting structure of balancing machines may be better understood after a consideration of a reed vibrometer such as is shown in front and sectional view in figure 11–20. Such a vibrometer has a base, **M**, carrying a number of spring reeds **R**. Attached to the free end of each reed is a weight, W, the face of which is painted a contrasting color for easy visibility against a black background. By proper proportioning of the cross section of the various reeds and by attachment of

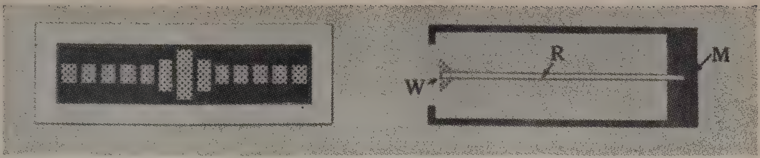


Figure 11–20.—Principle and construction of a vibrometer.

proper weight, each of them can be made to respond to a different and definite rate of vibration, this difference in rate or natural frequency being sometimes as little as five vibrations per minute. When the vibrometer is used for its usual purpose of determining rate of vibrations, the base of the vibrometer is held against the structure the vibration rate of which is to be determined. The vibrometer base then vibrates with the structure and only the particular reed with a natural frequency corresponding with the vibration rate of the structure will vibrate with pronounced amplitude while the other reeds remain essentially motionless. This is illustrated by the left or front view in figure 11–20.

A natural frequency is similarly present in the flexible work-supporting structure of balancing machines, since such work supports have the elements found in the vibrometer. That is—in the two common types of work supports shown in figure 11–21, A and B, for instance—there is a base M, a reed or spring R, and a weight W, which is the workpiece.

Thus we see, when the base of the balancing machine rests on a floor or bench which vibrates because of adjacent machinery at a rate corresponding to the natural frequency of the flexible work supports, that the workpiece and supporting structure will vibrate with large amplitude even when the workpiece is not rotating. In this circumstance the balancing machine in operation will indicate these vibrations in addition to those occasioned by unbalance in the rotating workpiece. This is a particularly aggravating circumstance with machines (generally called "critical speed" machines) which rotate the piece at a rate corresponding with the natural frequency of the work-supporting structure.

These critical speed machines rotate the piece at a speed corresponding with the natural frequency of the support, in order to obtain maximum amplitude of vibration for measuring purposes. Unfortunately, it is extremely difficult to tune the two supports to the same frequency, and maintaining rotation of the piece at such constant speed is impossible with available electrical drives. Referring again to the reed vibrometer and figure 11–20, it will be noted that slight variations from the critical speed result in pronounced reductions in amplitude and a corresponding reduction, with these critical speed machines, in the indication of the amount of unbalance. To restate: In critical speed machines, variations in the indication of amount of unbalance is caused by variation in the speed with which the piece is rotated as well as by vibration transmitted to the piece and support from the floor.

Some types of balancing machines carry the piece in supports as shown in figure 11–21B, and these supports, too, have a natural vibration frequency. But this natural frequency is low, never more, incidentally, than one-fifth the rotational rate for the piece. If vibrations of this low fre-

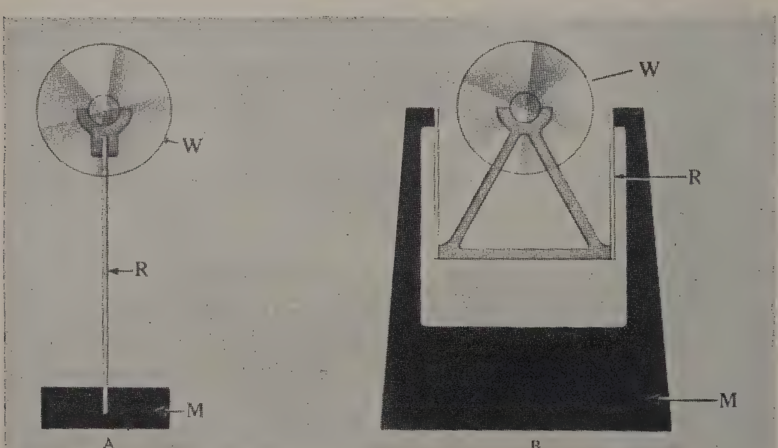


Figure 11–21.—The principle and construction of a balancing machine workpiece supports.

quency are transmitted from the floor and do appear in the piece and in the supports, they can be blocked by suitable filtering means incorporated in the amplifier of the electrical-network type of machine which blocks all frequencies other than the rotational frequency of the workpiece.

Small Lot Balancing

The work in a machine shop on board ship is primarily repair work in nature. In contrast to mass production of one item, or one class of items, in many civilian industrial plants, the repair activities in the Navy do miscellaneous repairs or small lot work. Therefore balancing machines that are used in the Navy must be so constructed that they can be quickly set up for any balancing job within their range. In general, each repair job will have its own individual setup in the balancing machine.

Drives for the Workpiece

The workpiece in any balancing machine is rotated by a driving device at one end or by a belt over the periphery of the piece, the latter means being more advantageous with smaller pieces, because the use of an end drive for rotating the piece presents certain difficulties, especially when small parts are being balanced to a high order of accuracy.

On certain types of balancing machines, both the belt drive and the end drive are provided. The belt drive is used for small workpieces and the end drive is used for large items. This ensures accuracy of balancing throughout the full range of the machine.

MEASUREMENT IN UNITS OF CORRECTION

Balancing machines ordinarily indicate the amount of unbalance in completely arbitrary units or in ounce-inches, in which event the operator must convert the measurement into terms of the correction means actually being used on the job—such as depth of drilling, length of wire solder to be

applied, the number of washers to be attached, or similar methods of adding weights.

In some types of balancing machines the conversion of the machine measurement to practical correction units can be made by the use of a "calibration constant," a number by which the machine indication is multiplied to determine the amount of correction units which must be applied. The possibility of errors in computations can be avoided by using prepared correction charts. Modern balancing machines are designed to eliminate any trial-and-error methods by the operator in making corrections. The amount of correction required may be shown directly on an amount dial in terms of the means actually being used—such as the number of $\frac{1}{64}$ of an inch depth of a selected size of drilled hole, the number of $\frac{1}{8}$ of an inch of wire solder, or the number of washers.

CORRECTION METHODS

While a good balancing machine will indicate the precise size of and exact location for correction, the balancing process is not complete until such corrections have been applied. These corrections are, of course, to be applied at the selected radii and in the selected correction planes.

The function and design of a workpiece will limit the methods of correction which may be employed. Of the methods possible with a particular piece, care should be used in selecting one which will give the greatest over-all accuracy and the best workmanship. Corrections may be made by the addition or the removal of material.

Correcting Unbalance by Adding Weight

When using balancing machines the common means for adding weight are: (1) the addition of a measured length of wire solder of a given diameter, (2) the addition of a measured length of strip metal of a given cross section, and (3) the addition of a selected size or a given number of one size of a known weight ordinarily made up as washers, lead slugs, or cast weights.

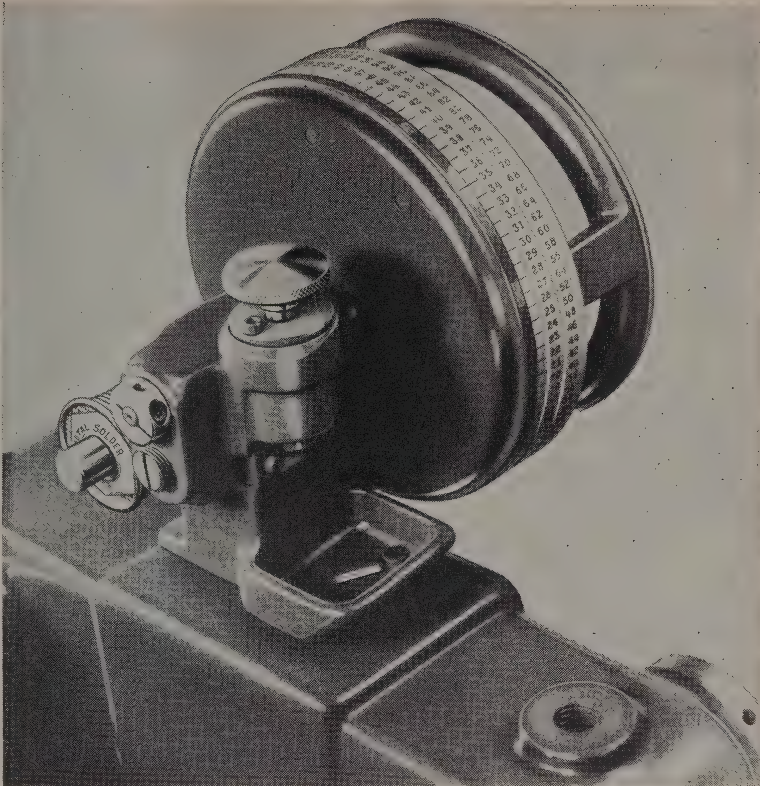


Figure 11–22.—Metering device for adding correction weights.

In the case of squirrel cage fans, for example, measured lengths of wire solder can be applied to the shroud rings; also, in the case of armatures for direct current motors and generators, the solder can be applied to the banding wires.

Figure 11–22 shows a device whereby the length of solder required for correction is metered out by turning the handwheel to a number corresponding with the unbalance indication of the balancing machine, and then is cut off into the tray with a light blow on the punch knob. Strip material of a given cross section may also be used.

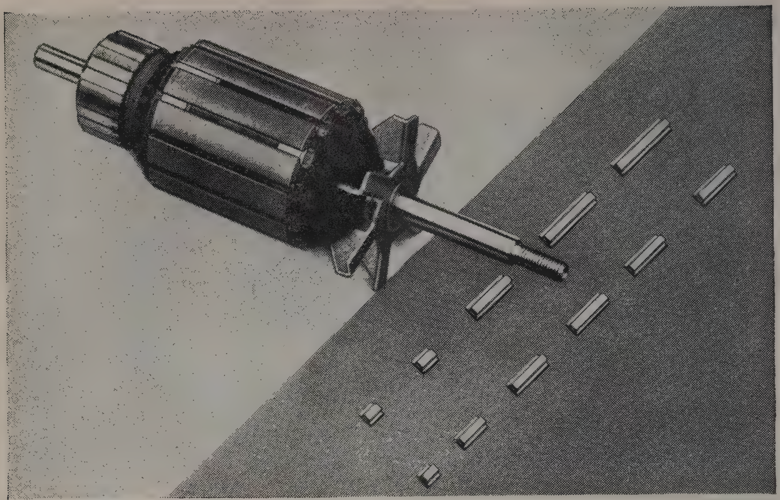


Figure 11–23.—A method of using correction weights for electrical armatures.

Figure 11–23 shows how strips of brass or aluminum may be used on small universal motor armatures. The extended material is pre-cut to various lengths which are multiples of the base unit of correction as indicated by the balancing machine, and inserted in the slots of the armature's cone.

Correcting Unbalance by Removal of Weight

The common means of removing weight are: (1) the removal of metal by milling, grinding, or shaping, and (2) the removal of metal by drilling.

Milling or shaping often do not give an accurate job because of variations in surface, especially with forged or cast pieces. The effectiveness of snag grinding is altogether limited by the operator's skill, and there is the possibility of burning the metal and destroying its quality, a condition which may extend into important machine surfaces. Drilling is usually the best means of removing metal for balance. The machine tool, suitable work-holding fixtures, and any needed guide bushings are comparatively inexpensive. A given diameter of drill to a measured depth will remove an

intended weight of metal with a high degree of accuracy. Precautionary measures must be taken in the location where metal is to be removed; otherwise, the strength of the rotating part or piece may be impaired.

BALANCING MACHINES USED BY THE NAVY

The importance of modern and practical balancing machines is recognized by the Navy for its repair activities. Special problems arise when balancing machines are installed on board ship. A moving ship does not have the solid and stable foundation comparable to that found ashore. For the best results in balancing, the work should be done when the ship is anchored or tied to a pier in calm water. A large amount of vibration is also present in a ship. This condition

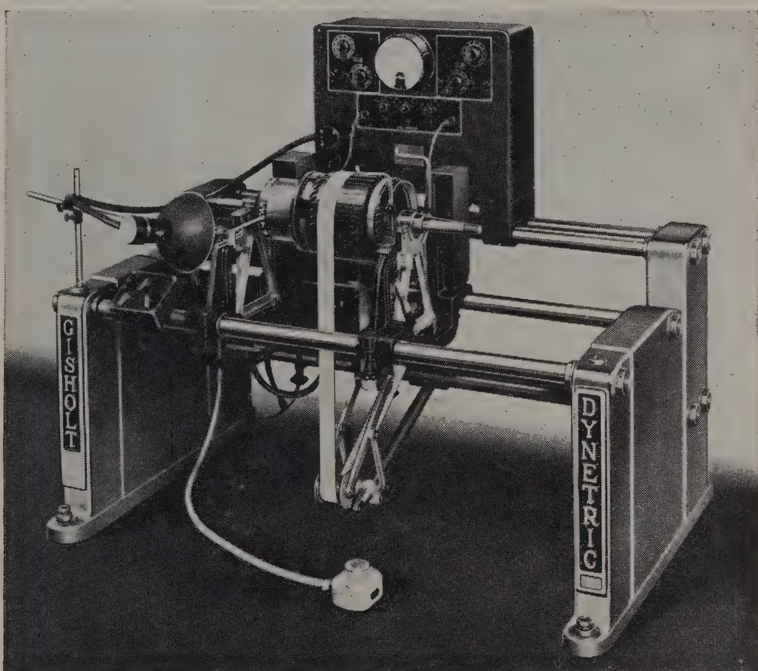


Figure 11–24.—The Gisholt Dynetric Type 3S Balancing Machine.

must be corrected and minimized as much as possible when doing balancing work. Because of the nature of the work, balancing machines should be so made that new set-ups can be readily made without undue loss of time. Balancing machines should be easy to operate and free from complicated procedures.

Figure 11–24 shows one type of balancing machine used by the Navy. This machine is arranged for balancing parts from 10 to 200 pounds in weight. It has a maximum diameter of 24 inches and a length of 24 inches between bearing shoulders.

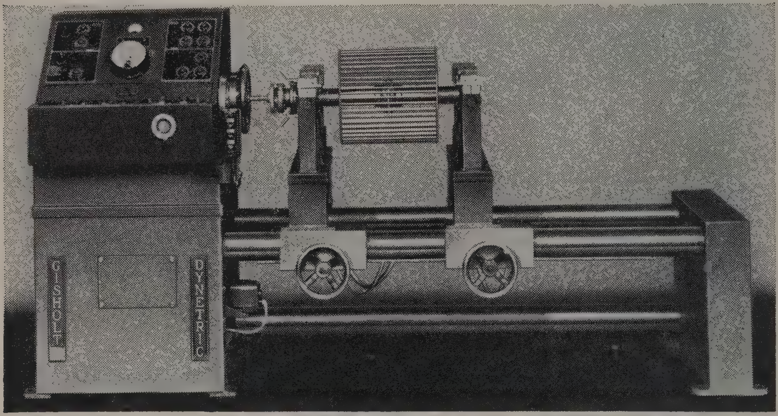


Figure 11–25.—The Gisholt Dynetric Type 4½ U Balancing Machine.

Figure 11–25 shows a machine arranged for parts from 75 to 1,500 pounds in weight. It will take parts up to 45 inches in diameter, and measuring as much as 72 inches shaft length from drive coupling to outer bearing support.

Figure 11–26 shows a machine that has a capacity for parts from 200 to 2,000 pounds. A similar machine is made with a capacity range from 10 to 250 pounds.

PORTABLE EQUIPMENT

The purpose of portable balancing equipment is to detect unbalance in large rotating parts, such as motors, generators, blowers, turbines, etc., without disassembly from their ma-

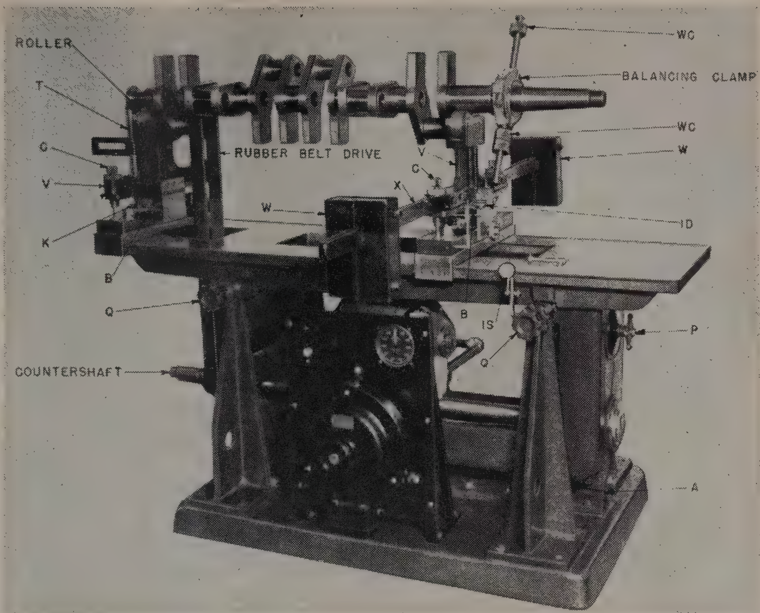


Figure 11–26.—The Akimoff No. 2–H Balancing Machine.

chines. There may be the possibility of making an easy correction without a major disassembling job, such as would be required if the rotating part were to be balanced in a regular balancing machine. The portable equipment can also be used in making tests or for maintenance of proper balance under actual operating conditions.

This type of test equipment will detect conditions of dynamic unbalance. This is accomplished by an indication of the amount of vibration together with an indication of the location of the unbalance in the machine. From these readings locations and amount of required corrective weights may be determined.

The portable equipment consists essentially of a carrying case with the various attachments and electrical connecting cords. There are various types of equipment manufactured for this purpose. One type is shown in the *Catalog of Navy Material* under testing equipment (Class 40).

QUIZ

1. Give a simple test that indicates that a body is in static balance.
2. Give a simple test that indicates that a body is in dynamic balance.
3. What is accomplished by applying the balancing process to a rotary part of a machine?
4. What are the general benefits that result when parts rotating at high speeds are properly balanced?
5. What are some of the ways in which the balance of machinery parts may be disturbed during repair procedures?
6. What is the most common cause of unbalance in a fan? In a pump impeller?
7. When an armature is being repaired, will careful rewinding ensure that the original balance will be restored?
8. If a casting of a pump impeller has been made so that the part appears exactly symmetrical, is a balanced condition thereby ensured?
9. A crankshaft and a flywheel are each in balance, but when they are bolted together, a condition of unbalance results. Explain.
10. What are the conventional terms in which unbalance is measured?
11. An unbalance of 1 ounce-inch produces a centrifugal force of 2 lb at 1,000 rpm; at 50,000 rpm will it produce a centrifugal force of 2 lb; 100 lb; 5,000 lb?
12. A part that normally rotates so slowly that it is not affected by centrifugal force, is out of balance; what type of balancing does it require?
13. If a flat disk has an unbalance of 15 ounce-inches, and if the weight causing the unbalance is 3 ounces, where should a corrective weight of 10 ounces be placed?
14. If the flat disk of question 13 were a cylinder of long axis, would the same method of correcting unbalance apply?
15. A cylinder with two equally heavy points, on diagonally opposite sides of the rotational axis, is in static balance when it rotates. Explain.
16. In general, where will weight be applied to a rotating part in order to bring it into dynamic balance?
17. The process of correcting dynamic unbalance usually consists of what two steps?

18. What must always be considered in selecting the planes in which to make correction for dynamic unbalance?

19. Is it possible for a balancing machine to indicate DIRECTLY the amount and the angular location of the required corrections?

20. If the cylinder in figure 11–8 were rotating, would it cause vibration at the B bearing only, or at both the A and the B bearings?

21. Can the unbalance be measured by the motion of the bearings alone?

22. In the device shown in figure 11–9, how is the measure of unbalance determined?

23. What is the disadvantage of using the pivoted cradle to measure unbalance?

24. In connection with the device illustrated in figure 11–10, how would you define "nodal point"?

25. What are two factors that detract from the value of the nodal bar as a device for measuring unbalance?

26. In the electrical network method of plane separation, what is the purpose of the coils and permanent magnets attached to the bearings?

27. How does the electrical network make it possible to read displacement SEPARATELY for the respective bearings?

28. If an unbalanced part is supported in a balancing machine by means of steel wires or springs, will its vibratory motion, as compared to its motion when rotating freely in space, be greatly increased? Greatly decreased? Negligibly decreased?

29. What are the three terms used to define the methods of measuring amount of unbalance (neglecting angular location of correction)?

30. Why is it that devices that measure unbalance by means of single or compound levers can follow only vibrations of low frequency?

31. What is the minimum unbalance that such lever devices are capable of measuring?

32. What indicating system is used to avoid these inertia and friction difficulties?

33. In the electrical network balancing machine, the optical lever, or the pivoted cradle, how is the stroboscopic lamp triggered?

34. Which does the stroboscopic lamp and reference pointer indicate more accurately—the location or the amount of the correction?

35. When a stroboscopic lamp is used, should the workpiece be rotated at speeds greater or less than 800 rpm?

36. With electrical network balancing machines, is a wattmeter used to determine the location or the amount of the correction?

37. How is the reed vibrometer used to determine the vibration rate of the work-supporting structure of a balancing machine?

38. What is indicated if the work-supporting structure of a balancing machine vibrates with noticeable amplitude even when the workpiece is not rotating?

39. Define "critical speed" machine.

40. Will slight variations from the critical speed result in an increase or in a reduction of the amount of unbalance indicated?

41. In critical speed machines, variations in the indicated amount of unbalance may result from what two causes?

42. A filter in the amplifier of an electrical-network balancing machine serves what purpose?

43. Which is better for use with small workpieces—belt drive or end drive?

44. Does the calibration constant indicate DIRECTLY the amount of correction?

45. Name three methods commonly used to add weight in correcting for unbalance.

46. What are the means commonly used in removing weight to correct for unbalance?

47. What type of equipment is used to detect unbalance in motors, generators, and turbines, without disassembling them from their machines?

CHAPTER 12

RUNNING A MACHINE SHOP

When it comes to running a machine shop, experience is the greatest asset. The chief petty officers who are supervising shops depend mostly on their past experience in shop work and repair procedures.

The intent of this chapter is to point out some of the things which must be considered by a person in charge of a machine shop. It would be impossible, however, in a book of this type, to cover all the procedures and problems that come up in the work of a shop supervisor.

By studying this chapter a first-class petty officer can become aware of some of the things that take place in his shop in regard to the job of setting up shop procedures and the methods by which everyday problems are solved by his leading CPO. A first-class petty officer who is alert and observant in his shop will gain invaluable experience for a future date when he may become a CPO in charge of running a machine shop.

CARE OF TOOLS AND EQUIPMENT

Manufacturers' instruction books cover all essential details of readying machines for operation, and for cleaning, lubricating, adjusting, and general care and maintenance. These instructions, supplemented by technical handbooks, provide comprehensive manuals on all phases of shop practice. Operating instructions and safety precautions should be posted at each machine.

Shop Housekeeping

An experienced person can make a quick survey for cleanliness, neat tool and stock stowage, and the condition of equipment. If such a survey reveals a high quality of housekeeping, it is safe to assume that the shop is well organized and that it really turns out the work.

Shop material and machine tool attachments must be stored in a convenient, secure, and orderly place. The stowage facilities must have adequate provisions for securing for sea.

If shop space permits and enough hand tools are available, each rated man should have his own stowage drawer or tool box in which he can keep the tools he ordinarily uses. Besides speeding up production of work, this method of stowage will provide better care and cleanliness of hand tools. Tool stowage is an important item in the shop.

Rust is a persistent problem on board ship. All bare metal surfaces should be kept clean and bright, and a light coat of machine oil should be applied to protect them. The rust-prevention program should be a part of the daily clean-up routine. A rust-preventive compound can be used on bare metal surfaces where applicable.

Cleaning and Lubricating

In order to ensure proper operating condition, at all times, of all power-driven tools on board, the following procedure should be observed during each weekly inspection (subject to postponement if weather conditions make it unsafe to release locking devices):

1. Remove or release all blocking and locking devices.
2. Wipe all exposed finished surfaces with a clean rag and remove any indications of rust.
3. Oil and grease the machine according to the manufacturer's instructions and apply a film of oil to the finished surfaces. A schedule should be set up for the lubrication of machinery in the shop. A form of check-off list should be used to ensure that all machinery has been lubricated according to the foregoing schedule.

4. Operate all carriages, tables, rails, heads, ram, turrets, etc., by hand to ensure that they are free to move before applying power, then operate the machine under power to the full travel of the various moving parts to ensure full distribution of lubricating oil.

Care of Material and Equipment

It is sometimes said that a machine tool operator can be judged by the condition of his tools and the kind of shavings on the deck.

The first part of the above statement refers not so much to the age or general appearance of the tools and equipment as to their working condition. For example, is the drill ground correctly? Is the head of the chisel smooth and regular, and is it sharpened properly? Is the machinery kept painted, are the speed and feed tables legible, are moving parts free of obstruction, is the machine adequately lighted, and are operating instructions and safety precautions well posted? If a specific job is being performed, is the right tool being used?

The second part of the statement relates to the manner in which the tools are used. An examination of the shavings or scrap sometimes indicates whether both tools and equipment were properly handled, and may answer such questions as: Was the metal over-heated? Did the metal lack plasticity? Was the metal incorrectly formed? Was the tool dull? Was too thick a cut taken? Was material wasted?

Proper care and maintenance of material, tools, and equipment are closely related to efficient, safe, and economic operation of the machine shop. If the Chief Petty Officer is negligent in maintaining an orderly shop or in training his men in the correct care and use of tools, materials, and equipment, it is very probable that accident, waste, and delay will result. The chief, in order to carry out his duties as a supervisor, must know the operation and the correct use of all the machine tools in his shop. He must see to it that men are qualified to operate a machine before they are allowed to run it.

The shop supervisor should observe the following rules relative to the care of materials, tools, and equipment:

1. Know what tools should be used for each job.
2. Know how each tool and piece of equipment should be used—for the basic principle of care is CORRECT use.
3. Know the hazards involved in the use of each tool and piece of equipment.
4. Know the operational procedure, the setting, the adjustments, and the load limits of each machine.
5. Know the characteristics of the material to be used.
6. Train each man in the proper use and care of tools and equipment, in the correct operation of machines, and in the proper care and handling of materials.
7. Diligently inspect the tools, equipment, and materials in use.

Inventory of Tools and Equipment

One of the jobs of the chief in charge of a machine shop is to keep a system of accountability for valuable tools and equipment. He should see that custody cards are made out for series 12000 (formerly title "B") tools and equipment. These include such items as portable power tools, gages, micrometers, and special sets of hand tools. Tools which are of a highly pilferable nature should be accounted for at regular intervals.

All series 12000 tools issued from the tool room should be returned at the end of the working day, unless special permission has been obtained to keep them out for a longer period of time.

In making a complete inventory of tools and equipment the BuShips Allowance Book for the ship is used. This book lists the equipment, accessories, tools, and spare parts furnished the machine shop.

SAFETY PRECAUTIONS

Precautions for Safety of Operators

The following precautions for the safety of personnel should be observed by the operators of all types of power-driven tools:

1. Do not attempt to operate a machine with which you are not familiar.
2. Before operating a machine make sure there is plenty of light to work by.
3. Do not operate electrically driven machines, either stationary or portable, without observing the proper electrical safety precautions.
4. Shut off the power supply to any machine that is being repaired or adjusted; and attach the prescribed warning card to the switch, to ensure that the machine will not be energized by other personnel.
5. Do not allow machines to run unattended.
6. Never lean against a machine that is running.
7. Keep machine guards in position at all times unless removal is authorized by the shop supervisor.
8. Replace machine guards after repairs or inspections have been completed and before the machine is started.
9. Do not distract the attention of a machine operator.
10. Do not wear loose or torn clothing, gloves, neckties, long sleeves, or rings while operating a machine.
11. If clothing becomes caught in a machine, shut off the power immediately.
12. When using portable electric equipment around machine tools, take special care that electrical cords are clear of moving parts.
13. When necessary, clamp workpieces securely to the machine.
14. Do not exceed the recommended depth of cut, cutting speeds, and feeds.
15. Keep the areas around machines clear of obstructions and in a nonslippery condition.
16. Remove chips with a brush or other suitable tool—never by hand or with compressed air.
17. Always wear goggles or a face shield when grinding, or when there is danger of flying chips.
18. Do not operate electrically driven portable hand tools without a ground connection between the metal housing

of the tool and the steel structure of the ship. If the tool is equipped with a grounded plug, be sure that the grounded plug is inserted in a grounded receptacle. If the tool is equipped with a 2-contact plug and a supplementary ground wire, be sure that the ground wire is securely attached to the ship's structure by a clean metal contact. Where the ground wire is independent of the tool plug, the ground wire should always be connected BEFORE the plug is inserted in the receptacle and should not be disconnected until AFTER the plug is pulled out. Where portable tools are provided with grounded plugs, this sequence of connecting the ground first and disconnecting it last is automatically provided for in the arrangement of the contacts in the grounded plug and grounded receptacle. It is, therefore, in the interest of safety and convenience to install these grounded plugs on all portable tools.

Precautions for the Maintenance of Machinery

1. Before applying power to a machine, be sure the machine is ready for starting. For example, move the carriage of a lathe by the hand feed to ensure that all locking devices have been released.
2. Do not lay work or hand tools on the ways of a machine.
3. Avoid scoring the platen of a planer, drilling holes in the table of a drill press, or gouging the vise or footstock of a milling machine.
4. Do not use the table of any machine for a work bench.
5. When using a toolpost grinder on a lathe, cover the ways and other finished surfaces to protect them against grit.
6. Be sure that pneumatic power-driven hand tools are lubricated after each 8 hours of operation, or more often where found necessary.
7. Before an electric power-driven hand tool is issued from the tool room, examine it carefully for mechanical and electrical defects.

8. When securing for sea, take all precautions to ensure that machinery or components will not sway or shift with the motion of the ship. These precautions should include the following:

a. In the case of top-heavy equipment such as a radial drill press arm, lower it to rest on the table or base of the machine and then make sure that it is locked and blocked securely.

b. Secure chain falls, trolleys, overhead cranes, and other suspended equipment, such as counterweights on boring mills and drill presses.

c. Secure tailstocks of lathes.

d. Secure spindles of horizontal boring mills.

e. Protect and secure tools stowed in cabinets or drawers. Secure drawers and cabinet doors.

REFERENCE BOOKS AND MATERIAL

Good handbooks and reference material are just as much tools of the trade for the Machinery Repairman as are precision measuring instruments, hand tools, and machine tools. A Machinery Repairman cannot possibly remember all details or data that he may need in his daily planning and work. A well-run machine shop will have a technical library consisting of machinist handbooks, the *Bureau of Ships Manual*, manufacturers' instruction books for all the machines in the shop, books on machine shop operations and practices, and various other books of reference or instruction. The Navy furnishes a certain number of books, and others can be purchased ashore. Many leading Machinery Repairmen prefer to buy their own handbooks.

A chief who is supervisor of a machine shop should check the shop's library to see that reference books are available. In accordance with the needs of the shop, he should make recommendations to his division officer for books or reference material that may be required.

Bureau of Ships Manual

The *Bureau of Ships Manual* is issued under the authority of *U. S. Navy Regulations* for the information and guidance of all persons in the naval service. Administration and technical instructions which are not included in *Navy Regulations*, but which are deemed necessary for a clear understanding of the requirements of the work coming under the cognizance of the Bureau of Ships, are given in this *Manual.* The data and instructions pertaining to the machinery installations of Navy vessels apply to the class of machinery under discussion rather than to exceptional members of that class. They are in accordance with what is considered the best engineering practice for the operation, maintenance, and repair of such machinery. In order to make the instructions clear, brief descriptions of type units on plants have been included. However, for complete information on details of design, machinery drawings must be consulted. For details of description, operation, adjustment, and care of machinery one must consult manufacturers' instruction books.

The Machinery Repairman should be familiar with BuShips *Manual* so that he can readily refer to it when questions come up in regard to machinery repair work.

It must be remembered that the data and clearances given in BuShips *Manual* are published merely as a general guide, to be used only in the absence of more specific data as given by manufacturers' instruction books and blueprints.

Bureau of Ships Journal

The *Bureau of Ships Journal* contains notes and articles of the type which formerly, before the establishment of the *Journal*, were contained in five separate publications—*Electron*, *Conservation Digest*, *Industrial Notes*, *Bulletin of Information*, and *Shop Notes.* It is recommended that the *Journal* be kept for reference purposes, and be made readily available to shop personnel.

The *Bulletin of Information*, *Shop Notes*, and *Industrial Notes* are described below, even though they are no longer

published separately, because they are still sources of official information.

Bulletin of Information

The *Bulletin of Information* contains articles originating in the various technical sections of the Bureau of Ships. These articles pertain to new machinery; research developments on new equipment; operating and maintenance procedures; and reports of casualties, with analysis of cause and preventive measures to avoid recurrence. The articles were formulated, to a great extent, from reports received from ships and shore activities. This publication is useful and interesting to the Machinery Repairman, and will add to his general knowledge of repair work. The *Bulletin of Information* was issued quarterly, and was kept for reference purposes.

Shop Notes

Shop Notes, NavShips 250–002, contains information submitted to the Bureau of Ships by the naval shipyards and repair activities. It includes description of new shop equipment, unusual repair problems and their solution, salvage operations, and notes on shop upkeep and administration. A great many beneficial suggestions submitted by shop personnel were also included in this publication. Fleet repair activities were encouraged to contribute articles for publication. *Shop Notes* was issued semiannually.

This publication offered technical information, on machine shop work and repair problems, which directly concerns the Machinery Repairman. By careful reading of this publication the men in a ship's machine shop can increase their knowledge and information concerning the practical and technical phases of their rating.

Industrial Notes

Industrial Notes, NavShips 250–741, are technical leaflets describing modern shop equipment and advanced production methods. Each issue deals with a distinct subject and includes a selected bibliography listing the latest authoritative

articles pertaining to the subject discussed. These leaflets, issued monthly, were given wide distribution to interested activities ashore and afloat.

Most of the articles in the *Industrial Notes* are of interest to the Machinery Repairman. This publication should be kept on file where it will be readily accessible to the shop personnel, so that they may read and study it during their leisure time.

Manufacturers' Instruction Books

Manufacturers' instruction books are furnished for machinery and equipment used by the Navy. Each ship keeps a file of manufacturers' instruction books for the machinery and equipment installed on board ship.

When repairs are to be made on machinery for a ship, the manufacturer's instruction book should, if necessary, be furnished to the repair activity. This book or pamphlet will give detailed and specific technical information on construction of the machinery, how to make adjustments, the way different parts of the machine are assembled, and the procedures for making inspections and repairs. The manufacturer's recommendation as regards clearances and methods of assembly and fitting of parts should be followed insofar as practical.

Manufacturers' instruction books for machine tools and equipment in the machine shop should be kept in a file. All shop personnel should have ready access to these instruction books, and the personnel responsible for the operation, care, and maintenance of the machine shop equipment should be thoroughly acquainted with their contents.

Blueprints

The Machinery Repairman must have a good knowledge of blueprints and an understanding of the method of filing and keeping blueprints in the Navy. Individual ships, tenders, and repair ships are furnished with plans, and with such microfilm as is available and applicable to ships that may be repaired by the tender or repair ship concerned.

The blueprint is a photographic print (blue, white, or any other color) used for copying drawings or plans.

All ships use the same system for filing blueprints, although the number and type of plans carried will be different on different ships. The number assigned to a blueprint for identification and filing purposes is composed of several groups. For example, in the Bureau of Ships plan number CA139–S5101–525802, the group CA139 is the class ship designator. It is the CLASS of ships for which the plan applies. The next group is S5101, which is the "S" (subject-matter) group or material file number. In this example, the reference is to a blueprint on the general arrangement of a boiler front. The group 525802 is the individual plan number. Another example of a plan number is DE51–S4602–1, where DE51 is the ship class, S4602 is the subject-matter filing number (in this case condensers), and 1 is the individual plan number. In other words, it is the first plan under the S4602 group for DE51 class of ships.

In cases where an alteration or change has been made, the blueprint will have an alteration number also. For example, in blueprint number CA139–S5103–528155 Alt. 4, the "Alt. 4" is the alteration number. If all the alterations have been completed, the plan with "Alt. 4" is kept on file and the previous ones (Alt. 1, Alt. 2, and Alt. 3) are disposed of.

Care must be taken, when working from blueprints, to see that you have an up-to-date plan and not one that is obsolete. This can be done by checking on the "Alt." numbers. In case the last alteration has not been completed the ship concerned will keep two blueprints on file until such time as the alteration has been completed. In this example the two plans would be CA139–S5103–528155 Alt. 3 and CA139–S5103–528155 Alt. 4.

Since this system of classification, or filing, of blueprints has been in use only since May 1944, you may encounter some of the older blueprints. A plan number assigned before 1944, for example, might be "476719 Alteration 2." Plans like this should be assigned their proper S group filing

number. This particular plan (476719) would be filed under the S2600 group, since it is a plan for the a-c controller for the anchor windlass.

You must have an understanding of the S or material group classification and numbering system because it is used in the filing of blueprints. The listing of filing numbers and their subject matter is given in the *Navy Filing Manual.* The same system is used for numbering the different chapters in BuShips *Manual.* This relationship is illustrated in the following table:

Subject Matter	File Number, Filing Manual	Chapter Number, BuShips Manual	Material Group, Blueprints
Main Propelling Machinery	S41	Chapter 41	S4100
Condensers and Air Injectors	S46	Chapter 46	S4600
Pumps	S47	Chapter 47	S4700
Boilers	S51	Chapter 51	S5100

Each ship has a list of the plans that are furnished to the ship. This list of plans is called the "Ship's Plan Index." Ships may also have a typewritten index of the plans that are carried on board. The use of an index is the best method of finding a blueprint on board a ship. Assume that repairs were being made to a main feed pump and a blueprint was needed. The proper procedure would be to go to the engineer log room and obtain the Ship's Plan Index. If you know the filing number for pumps, you can immediately turn to the S4700 group. Here you will see listed the numbers and titles of the various blueprints on pumps. From the listed titles you can usually spot the blueprint you want. The number opposite the title is noted down. The next step is to go to the filing cabinets where the blueprints are stowed. The file drawers are labeled with the S-group numbers and the numerical plan number sequence of the blueprints in the drawer. Look for the file drawers marked S4700 and then check for the numerical sequence that the desired blueprint

would come under. For example, if the individual plan number of the desired blueprint was 527903 and the file drawer marked "S4700—527807 through 528014" was located, you would know that the desired plan was in this drawer. The individual blueprints inside the drawer are usually in large manila envelopes with the number and title in the upper left-hand corner, and are filed in numerical sequence. By following this sequence, it will be a simple matter to locate plan number 527903. The blueprint is removed from the manila envelope, which stays in its proper place in the file, and checked over to make sure that it is the plan that gives the required information. In order to keep track of all plans removed from the files, the plans should be signed for, either on an index card or in a book kept for that purpose.

Technical Information

In carrying out his everyday duties, a Chief Machinery Repairman will need to have a considerable amount of technical information in the field of his specialty. He should also have a thorough understanding of the techniques involved in carrying out his supervisory responsibilities. These might include job planning; organization of the work, production methods, and work layout; the issuance of orders, directions, and suggestions; and a knowledge and understanding of the requirements related to working conditions, including proper lighting, ventilation, and heating.

Although the supervisor may to some extent lose the skills required for the actual performance of shop work, he must maintain and develop the technical knowledge required to supervise the work and see that it is carried out properly. He must possess all the technical information necessary to guide his subordinates in executing their assigned tasks, and his technical knowledge must be more comprehensive than that of the men under his supervision.

The Chief Machinery Repairman must be able to provide his superiors with accurate and complete information concerning the work for which he is responsible. He should be

qualified to discuss intelligently the work in fields allied to his own. To do this he must be constantly alert for new sources of technical information.

The supervisor in any field will find it an excellent procedure to frequently analyze his own duties and responsibilities. For example, a Chief Machinery Repairman might classify his various duties and responsibilities according to types, as:

1. Materials and Equipment.
2. Job Planning.
3. Training Needs.
4. Operations, Methods, and Procedures.
5. Personnel Relations.

A chief in charge of a machine shop should have some knowledge of the procedures and methods employed by people in outside industry, in jobs comparable to his own. If you cultivate the habit of reading carefully selected technical journals and naval publications, you will find yourself acquiring a store of extremely useful technical information.

PLANNING

Planning, as the term is used here, refers to the kind of planning which every Chief Machinery Repairman must do in the course of performing his everyday work. Planning is an essential part of any job, large or small; and lack of good planning usually results in confusion and delay. The CPO must plan for the coordinating of various steps in the work, and the meeting of deadlines. This involves consideration of manpower, equipment, and materials.

Several questions must be answered concerning the available manpower. How many men will be needed for the job? How much and what kind of skill is possessed by the men available for the job? What may be done to ensure the maximum utilization of their skills?

The use of equipment must be planned. What equipment is available? What is its condition? What is its capacity? What are its weak points? When was it last used? Are

there any unusual features of the job being planned which will adversely affect the utilization of the equipment? It will be seen that some of these questions involve problems of maintenance and upkeep, and that a long-range maintenance program is essential if the equipment and machinery is to be available whenever it is needed.

Usually the CPO in charge of a machine shop will have to do some planning in regard to materials. What kind of material, and how much, will be required for the job? What is the availability of the material? Is there a sufficient quantity on hand? Has the same kind of material been used previously for similar jobs? If not, does its use create new requirements of skill or equipment? Does it require special handling? What are the characteristics of the material, insofar as they will affect the over-all plan for the job?

In planning a job the CPO should first perform each step mentally, to work out the best sequence. This procedure will help to prevent the unintentional omission of some part of the job. Once the steps are outlined, consideration should be given to each step to make sure that all requirements are taken into account. Next in order is the question of timing and coordination; this requires that the longer operations of the job be started before the shorter operations. When considering the time factor in relation to manpower, it is well to remember the law of diminishing returns: adding additional men to the job may cut the total time but in some cases it may result in confusion and delay.

Once the planning is finished, follow the plans carefully. However, it is also necessary to be flexible, in order to meet unforeseen circumstances or emergency requirements. If changes seem to be indicated, it is the chief's job to reevaluate the total plan and, after careful consideration, to make such changes as he believes to be required.

It is also important to remember that if the men who are actually doing the work are kept informed as to the total plan, they may be in the best position to recognize impending trouble. It is therefore advisable to give the men as much

information as possible concerning the whole job, and to be ready and willing to listen to their suggestions.

Planning alone will never accomplish a repair job: follow-up is just as important. Make your plans practical and workable, and then see to it that they are put into effect. It is the CPO's job to see that the work gets done. If the job is simple, the problem of getting it done may also be relatively simple; but if the work is complex or if it is being done by a number of different men at different locations, then it may be necessary to set up some kind of a control system for determining work progress and work status.

In the last analysis, every chief is measured by the amount of finished work his shop is able to turn out. Careful planning will enable you to run your machine shop efficiently and productively.

LAYING OUT AND ASSIGNING WORK

A Navy machine shop is primarily concerned with repair work. The assignment of work changes constantly, according to the amount and type of work being done in the shop from time to time. Although there is no set procedure, work is generally assigned to the man and to the machine best fitted to handle it. Also, care is taken to see that the work is distributed so as to keep it flowing smoothly without piling up around one machine.

This means that a Chief Machinery Repairman in charge of a machine shop must be thoroughly familiar with the men and the shop equipment, so that he can plan and schedule the repair work. Reassignment of work may be made at various times to prevent delays, to accomplish added new work, or to expedite emergency jobs. This supervision requires years of practical experience and real executive ability, and the chief who can keep work running smoothly through the shop deserves substantial recognition.

Information on Incoming Work

When a new job order comes into the shop the Chief should check it over carefully to see that he has all the necessary

information. Although many of the jobs are considered routine, there are some that will need careful consideration and detailed planning.

In many cases it is necessary to have the blueprints for the equipment being repaired or for replacement parts that have to be made. Usually the activity requesting the work will provide the necessary plans. Repair ships and tenders are usually furnished with blueprints and microfilm applicable to those ships that may be repaired by the tender or repair ship concerned. The Machinery Repairman on a repair ship or tender can check his shop blueprint index to see if a required plan is carried on board his ship.

Another source of information is the manufacturers' instruction books. Modern naval ships are required to have these instruction books for the machinery and equipment installed on board ship.

Other reference publications, such as BuShips *Manual*, engineering handbooks, and machinist handbooks, are useful in obtaining detailed information.

The necessary information must be on hand before a job can be properly started.

Priority of Jobs

In planning and scheduling work in the shop, you will have to consider the different priorities of the job orders, such as urgent, routine, or deferred.

Deferred jobs do not present a problem, as they are usually accomplished when the workload of the ship is light and there are no jobs of a higher priority to be done. Also, when these jobs are approved it is with the understanding that they will be accomplished only if the time and shop personnel and equipment are available.

The majority of the job orders will have the "routine" priority assigned to them. Routine jobs make up the normal workload of the shop, and must be carefully planned and scheduled so that the daily organization and production can be maintained at a high standard.

The "urgent" priority jobs require immediate planning and scheduling. Other jobs, of lower priority, are set aside so that these urgent jobs can be processed through the shop. It may be necessary to assign extra men to the job at nights in order to complete some of these jobs on time.

Available Material for a Job

When a job order comes into the shop, one of the first things to be done is to check on the material or repair parts which will be required to complete the job. If a new pump shaft has to be made, the chief in charge should check to see that stock of the right type and required amount is available for the job. If a piece of machinery requires repair parts a check should be first made to see if these repair parts are available. The activity requesting the repairs may have the repair parts on hand or the repair parts may be carried by your ship. Sometimes when parts are not available, new ones have to be made or temporary repairs made to the old ones. Matters of this nature must be cleared up before the job is laid out and assigned to less experienced personnel in the shop.

Sometimes when a certain metal stock is not on hand, substitutions have to be made in order to complete the required job. The chief in charge of a repair shop must have a good knowledge of metals in order to make proper substitution when necessary. As a rule a metal of a higher specification is picked to ensure satisfactory performance.

Determination of Required Repairs

After inspection of the piece of machinery or equipment, you will determine what kinds of repairs or replacements are required and the best way of getting the work done. Some of the jobs that come into the shop require expert knowledge as to what should be done and how it should be accomplished. This is where good practical experience and up-to-date knowledge on different types of repair procedures are invaluable. Sometimes when planning a job it is a good idea to

check with some of the leading petty officers in the shop, as one of them may have done the same job before. Some of the planning work may be assigned to others; for example, a job of laying out a gear may be given to a man in the shop who has demonstrated his ability to do this type of work.

At times, the chief in charge may have to draw detailed sketches of a part to make sure that the man who is to make the part will have sufficient data so that he will not misunderstand his instructions.

Scheduling of Work

The main object in planned scheduling of work is to have the work flow smoothly and to have the next job ready without delay, since lost time between jobs lowers the over-all efficiency of the shop. In order to keep the work flowing smoothly, you will need to know what men and what machines will be available for the different operations that have to be performed.

The assignment of jobs in the machine shop is one of the major factors in obtaining a well-planned schedule of work in the shop. The more complicated jobs are assigned to the higher rated men, whereas minor and low-priority jobs are given to the relatively inexperienced personnel.

Usually the jobs that require the longest period of time are started at once and kept in progress in order to have them completed on time. The smaller jobs are given to the remaining unassigned machines and also are dovetailed into the schedule so that they can be done as soon as machines and personnel become available.

The priority of job orders, as well as the length of time required to complete them, will determine the scheduling of work. Jobs of urgent priority will be accomplished first before routine jobs are started. The deferred jobs or the jobs of least importance are left to the last; then they can be done or cancelled, depending upon the workload of the shop.

It may be necessary to change the schedule of work in the

shop when new high-priority jobs come in. Sometimes other work must be temporarily set aside until these urgent jobs are completed.

Experience, judgment, and foresight are required to maintain an organized scheduling of work in a large machine shop, in order to get the numerous jobs finished at their respective times.

ESTIMATING TIME FOR A JOB

From time to time the chief in charge of a machine shop will be called upon to furnish the division officer, and in many cases the repair officer, with an estimate of the time necessary to accomplish a certain repair job. "How long will it take?" is a routine question asked by personnel bringing material to shop for repairs or replacements.

For most of the routine jobs coming into the shop, or being processed by the shop, the CPO in charge may give a quick estimate of the probable time of completion. There is generally no necessity for completing routine repair jobs within any set time, and no need for extreme accuracy in estimating the required time.

However, for an urgent job—if a last minute job comes up near the end of the repair period for a ship alongside the tender, for example, or if a ship in port for a day or two requires an urgent repair job before starting out to sea—the time required to make repairs may be an important consideration. The time estimate must be accurate in such cases, to avoid the waste which would result from starting a repair job which could not be completed. Frequently the final decision will be made by the CPO in charge of the machine shop; because of his experience in repair work, his knowledge of the current workload, and his knowledge of the men and machines in the shop, he should be able to give a fairly accurate estimate of the time required to do a certain repair job.

Required Information

Before any estimate can be made, detailed information on the job must be on hand. Where necessary, blueprints and

manufacturers' instruction books should be studied. If possible, the item requiring repair should be thoroughly inspected because the job may require repairs or replacements in addition to those originally mentioned.

A decision has to be made as to the amount of repair work that is to be done. The detailed procedure in accomplishing these repairs must be clearly understood. In other words, one should have the complete information on all the details of the repair job before starting to consider the length of time which will be required to do the job.

Required Priority

The job under consideration, where an accurate estimate of time is required, must have a high priority in comparison to other jobs that may be in the shop. If the shop has a light workload and is doing only routine jobs, there will be no difficulties in processing a new job. On the other hand, if the shop has a heavy workload with several urgent jobs being done, the new job must have a higher priority because some of the other jobs may have to be set aside. If it is assigned a lower priority, it may have to wait until some of the jobs in the shop have been completed. Any delays resulting from the low priority of the job under consideration must be added to the total time of completion.

The priority that the job under consideration will have in the shop must be decided before any realistic estimate can be made.

Workload of Shop

The workload of the shop must be carefully considered before a new job is approved for completion within a certain time.

After a decision has been made as to what repairs or replacements are necessary, the chief will be able to determine what machine tools and personnel should be used for the job. The next step is to check on the present and scheduled work for the machines to be used. If a top priority has been given

to the new job under consideration, then the work being done by the required machine tool(s) will be set aside until the proposed job has been completed. If the new job does not have a top priority it must be dovetailed, in accordance with its priority, into the schedule of work being done by the required machine(s). In this case an additional estimate has to be made as to how long it will take before the machine(s) will be made available to start on the job under consideration.

Another decision must be made concerning the personnel to be assigned to the new job. This new job may call for experienced personnel who may have to be taken off other jobs; or again, it may be a routine job where the same machine tool operators may be used without any shifting of personnel. If the new job is a complicated one, a leading petty officer may have to be assigned to process the job through the shop, including disassembling, inspections, assembling, and tests. The number of required personnel, as well as their technical ability, must be considered.

Another item that must be decided is the number of hours per day that will be assigned for personnel to work on the new job. If it is to be a routine job, normal working hours will be considered. If it is a rush job with top priority, 3 shifts will be assigned to the job and men will be working 24 hours a day on it.

In summary, the selection and assignment of personnel and machine tools depend upon the magnitude and complexity of the new job under consideration as well as its assigned priority. This in turn depends upon the workload of the shop, except in cases where the new job is given top priority.

Required Parts and Material

After a decision has been made as to the extent and nature of repairs that are required, a check must be made to see if the required material and parts are on board ship. The material must be available before an attempt is made at

estimating the time of a repair job. In a case where a pump shaft has to be made, the chief should have someone check the storeroom to make certain that the right size and type of metal stock is on hand. Such items as gaskets, studs, bearings, and shaft keys that may be required must not be overlooked.

Naval ships carry an allowance of spare parts for machinery and equipment on board ship. A check of the manufacturer's instruction book, the ship's allowance book, or the repair parts allowance records will show if a certain part is carried on board. There are cases where this check has been overlooked by the ship or activity requesting repairs. There is certainly no need to manufacture an item such as a gear if the ship carries spare gears for the machine or equipment that requires repair. Locating available spare parts will save a great deal of time in doing the repair job, and one's estimate can be made accordingly.

Other Repair Shops

After the nature and extent of the repair job has been determined, you must find out what part of the work will have to be done by other shops. If a new casting is to be made, for example, the services of the patternmaker and the foundry will be required; or perhaps the electric shop may have to do some part of the repair job. You will have to consider not only the actual time required by these other shops, but also the time which may be lost if one of them holds up the work of the machine shop.

The chief in charge of the machine shop usually estimates the time required for the work which is to be done by his own shop. However, he should not attempt to estimate any work which is to be done by another shop; instead, he should obtain such estimates from the appropriate shop personnel. All aspects of the repair job must be clearly understood before any accurate estimate of the required time can be made.

Consideration of Things That May Go Wrong

Experience is an excellent teacher of things that may go wrong when doing a repair job. An experienced chief can avoid many of the difficulties that may come up in performing repair work. When planning and estimating a repair job the possible difficulties that may come up should be carefully considered and extra time allowed for them.

It is easier to avoid mistakes and delays if you have sufficient information before starting the job, and a clear view as to total amount of repair work that will be required. Adequate blueprints or other drawings should be on hand.

The repair job itself may cause a certain amount of breakage or damage. For example, when steam machinery or fittings are being repaired, some of the studs will break instead of coming out; and the CPO who has estimated half an hour for removal of the studs may find that the whole job actually takes four hours.

Failure to make the machine tool operator understand the details of the work may result in spoiled work. The chief may have all the details on the job, but this won't do him any good if the man doing the job ruins it because of lack of information or a misunderstanding as to what should have been done. The chief must make sure that the detailed instructions are thoroughly understood by the men doing the actual work. Some relatively inexperienced men fear to appear ignorant and want to make a good showing by saying that they understand the instructions without fully appreciating what is meant. When the job, or part of it, has to be done over again, the original estimated time of completion will no longer hold true.

When the unit that is to be repaired consists of a number of assembled parts, as in the case of a pump or an auxiliary turbine rotor, there may be difficulties in removing the various parts. Parts may be rusted or frozen so that it is extremely difficult to remove them. On the original inspection of the item in need of repairs, the chief should watch for any indication that the unit may be difficult to disassemble.

Then he should make an extra allowance of time in his estimate to cover this phase of the repair job.

If an item fails to pass any required tests after repair, additional work will of course be necessary. The required tests and the possibility of additional work associated with the tests must be considered when making an estimate of time required for the repair job.

When repairs are made to high speed rotating machinery, the repair work itself may unbalance the rotating assemblies. If there is any doubt of the original balance or of how repair work will affect the balance, plans must be made to balance the unit upon the completion of repair work; and the time required for balancing should be included in the total estimate of time.

The time required to deliver the piece of machinery or equipment to the shop should not be included on estimated time to do a repair job in the shop. When boat and crane service are involved in a proposed job, this fact should be brought up for consideration by the person or activity requesting an estimate of the time required by the machine shop. When requested to estimate this time of transportation, the CPO in charge of a machine shop should make an estimate distinct and separate from that of the one of his own shop. Boat and crane service may be unpredictable at times, and the CPO should check with the officer of the deck and the crane operator before making an estimate of this kind.

When planning on the required personnel for the job, a check should be made for the possible inspections, drills, and working parties that may come up which will delay the repair job. If the assigned men cannot be excused from these activities, extra time must be added for the completion of the repair job.

The above is not a complete list of things that may go wrong on a repair job but it will indicate the type of thing that may go wrong, and which will have to be considered when estimating the time required to do a repair job.

Estimating Time

There is no set rule for estimating the time that a repair job will take. Many different types of repair jobs are accomplished by machine shops in the Navy; and, although many types of jobs are repeatedly done in the shop, each job requires its own investigation and estimate of required work and time.

The method of figuring out the actual number of hours or days required to do a certain job depends a great deal upon the individual concerned and on his experience. Any method that produces the required results is a good one. The relatively inexperienced person will probably find it best to divide the total repair job into the various phases or steps of work

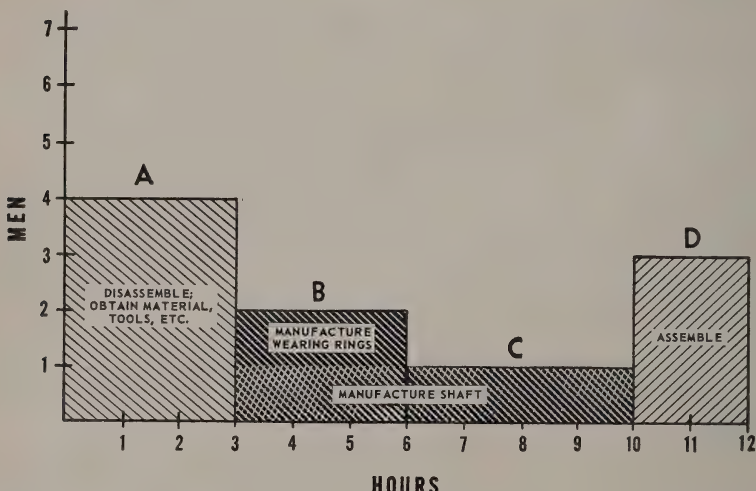


Figure 12–1.—Estimate of time required for a pump repair job.

that have to be done on the job, to make separate estimates of the time required for each step, and to add these estimates to obtain the total time required for the complete job.

In estimating the total length of time required to complete a job, you may find it helpful to draw a diagram or chart showing how many men can be assigned to each step of the

job, and how long each step is likely to take. Figure 12–1 shows a chart made up to estimate the time required for a pump repair job.

The graph shows that step A requires 3 hours; step B requires 3 hours; step C, 4 hours; and step D, 2 hours. ADDING THESE FIGURES GIVES YOU THE LENGTH OF TIME REQUIRED FOR THE TOTAL REPAIR JOB—in this case, 12 hours.

The diagram shows something else, too—the number of man-hours which are required for each step. If you add these up—12 man-hours for step A, 6 for step B, 4 for step C, and 6 for step D—you get a total of 28 man-hours required for the whole job. But what does this mean? Does the number of man-hours tell you how long the job is going to take? Is it safe to assume that the job requiring 28 man-hours can be done in 4 hours, if you assign 7 men to it? Obviously not, since there is a limit to the number of men who can work on the job at any given time. (Manufacturing the shaft, for instance, is in itself a 1-man job requiring 7 hours.)

The unit "man-hours," then, is a measure of amount of work, but not of time. You should be very cautious in using "man-hours" when estimating how long a job will take, because this measure does not allow for the sequence in which the work must be performed, the number of steps required, or the number of men who can work on the job at any given stage.

SUPERVISING REPAIR WORK

One of the most important duties of a Chief Machinery Repairman is that of supervising the repair work in the machine shop. The Chief must instruct shop personnel concerning the different repair jobs which have to be done, he must check on the progress of the work and give additional advice or instructions when necessary, and he should check the completed job to see that it has been done properly and in accordance with his instructions.

After the CPO in charge of the machine shop has obtained complete information on a new job and has decided what repairs or replacements are necessary, he must then decide

who is to do the job. In order to make this decision, the Chief must know what experience the men have had with different types of repair work, and what skills they have in operating the various machine tools.

When the workload in the shop is light and plenty of time is available, the Chief can assign new jobs to relatively inexperienced personnel in order to give them training and experience. On the other hand, if a job must be done in a short time, the Chief will naturally assign it to one of the best men in the shop. In the usual routine assignments, the more complicated and difficult repair work is given to the higher-rated men and the smaller and less difficult jobs are given to the lower-rated men. The assignment of a new job also depends a great deal upon the availability of the machine tools and the personnel.

The Chief in charge of the shop should see that all items coming into the machine shop are properly tagged. The men in the shop should be instructed to replace any tags which have been removed in order to do machining operations. The mix-up of some items, such as valves, can cause a lot of unnecessary confusion and lost time.

Starting the Job

The man who is going to do the repair job must be given detailed information on how the job is to be done. The CPO should be careful to see that the man fully understands what he is going to do, so as to prevent any mistakes due to misunderstanding of instructions. The amount of instruction depends upon the knowledge and experience of the man concerned. If he is an experienced rated man, it may only be necessary to give him a blueprint and tell him what parts have to be made or what repairs have to be accomplished. Inexperienced men will need additional instructions for setting up the work in the machine, and information on the proper procedure in doing the job. Men in the shop should understand that they are free to ask any questions in case they are in doubt about any details in doing their assigned

work. Men will ask questions when they see that it is to their advantage to do so.

In addition to giving instructions on how a job should be done, it is also advisable to give the men some information concerning the importance of the job, the origin of the job, the part that each person will play in accomplishing the complete repair job, and the reasons for certain specifications. Men are as much interested in why a job is done as in how it is done, and will usually turn out better work if they have a clear picture of the total job.

Checking Progress of Work

The chief who is in charge of a shop must know his men. He should have a pretty good idea of the skill, ability, and knowledge of each man in the shop in regard to operating machines and doing repair work. The best way the Chief can obtain this knowledge is to get around the shop frequently and find out what is going on. At the same time he can keep posted on the progress of the various jobs in the shop.

The assignment of a job is only the first step in processing a job through the shop. There are many things that a chief should constantly check on. Knowing his men, the CPO will have a good idea as to which jobs or which men will require the most checking or inspecting.

It is always a good practice to make sure, before a job is set up, that the right type of material is used and that it is of the proper size. The selection of the wrong material or the wrong size of material are two common errors that the chief should be alert to check on.

When checking on the progress of work, the CPO should be sure that the men are observing proper safety precautions in regard to themselves and the machines that they are operating. He should see that each man is using the proper tool and machine set-ups, and note the quality of work being produced. In case of any doubt the chief should check with a man to see that he understands his instructions properly or that he is doing the work correctly as indicated by his blue-

print or drawing. He should give additional instructions, if necessary, in order to give a better understanding of the job, or to improve workmanship. By frequently talking to the men and answering their questions, the chief can prevent jobs from being spoiled, as might be the case if he were not available to give the correct details on the jobs.

By observing the progress of the various jobs, and whether any are ahead or behind the planned schedule, the CPO will be able to change the schedule of some jobs in order to prevent bottlenecks and to keep the most important jobs moving. Complications may develop on some repair job which may require additional planning and revised repair procedures.

The chief who has interest and confidence in his men and their work will find that men have confidence in him as a good shop supervisor.

Checking on Completed Jobs

When a job has been completed in the shop, the CPO in charge should inspect and approve the job. Inspection is necessary to ensure that the repair job or the manufactured replacement parts will be satisfactory both to the repair activity and to the ship's force that are going to use and depend upon the machinery or equipment that has been repaired. Inspection of repaired machinery or manufactured replacement parts may be accomplished either visually or by means of measuring instruments. In addition, when applicable, shop tests are performed to check the satisfactory condition of repaired equipment or machinery.

On the chief in charge of a repair activity rests the responsibility for determining whether the repair job, including replacement parts, meets certain conditions that might be briefly listed as follows:

1. Have all the machining and finishing operations been completed?
2. Have the repaired or manufactured parts been correctly formed and accurately dimensioned in accordance with detailed instructions or blueprints?

3. Is the repaired item or replacement part free from defects in the material and workmanship?
4. Have all parts or accessories to the repaired equipment or machinery been replaced or returned with the repaired unit?
5. Have all items such as screws, bolts, studs, keys, lock washers, gaskets, and packing been replaced or renewed in accordance with original instructions?
6. Where applicable, has the part or item been properly checked for any unbalanced condition?
7. Has the proper material been used in making repairs or replacement parts?
8. When required, has the part been heat-treated?

The above are some of the things a chief must consider before the job is written up as completed and ready to be removed from the shop. No one should let work leave the shop until he, and the person receiving it, are satisfied with it. The men, as well as the chief, should take pride in their workmanship.

The completed job order should show the man-hours, material used, and a full description of the work accomplished. See that the necessary shop records and paperwork are correct and up to date. When the job has been completed, the interested parties should be notified as soon as practicable; completed jobs should not be left to accumulate in the shop, as some of the items may become mixed up, damaged, or lost.

Before releasing a completed item the shop supervisor should check to be certain that: (1) the correct job order is signed by a representative of the requesting activity, (2) the identification on the item and on the job order coincide, and (3) all manufacturers' instruction books and blueprints furnished with the job order are returned.

SUPERVISING A MACHINE SHOP

Chief Petty Officers, especially those who are in direct contact with the men, often fail to recognize the fact that they are part of the ship's administrative organization. Every

chief in the shipboard organization is definitely part of the administrative group. As such, he has delegated to him many responsibilities which he is expected to carry out by interpreting and executing the established policies and procedures. He can accomplish this properly only when he has a clear understanding of these policies and procedures and his true place within the organization.

His duties are of two types, supervisory and managerial. As a supervisor he is expected to spot operating difficulties in his shop, and in his managerial capacity he is required to do something about them. To execute these responsibilities he must understand his department and ship organization and the proper channels and lines of authority which are open to him. The further up the organizational chain that a petty officer progresses, the greater become his administrative responsibilities.

Duties of a Supervisor

The job of a supervisor is many-sided and has a particular importance with respect to the operation of any naval repair activity. A weakness in the performance of any supervisory duty or responsibility reduces the effectiveness of the whole job of supervision.

A chief cannot do a good job unless he does a complete job. In order to attain this end he must know all of his principal supervisory responsibilities; otherwise he is in the same class as a machinist who does not know all of the principal parts of his trade.

Obviously, then, the Chief Machinery Repairman in charge of a machine shop should fully appreciate and understand the responsibility he holds as a member of the repair organization, and be able to identify each of his duties with respect to the whole—not an easy task in a field so complex and variable as the work of a supervisor. Therefore, only by study and analysis of each part of his job can he expect to prepare himself to execute these many duties effectively.

Some administrative personnel have made long lists of the

responsibilities of machine shop supervisors. A close examination of such lists might disclose to each CPO points of difference as well as points of agreement. Many of the differences are of minor importance, but others represent real differences in responsibilities. After such a comparison it might be concluded that an accurate list of duties for any given job can be made only by the individual occupying the particular job. The following list, although suggestive rather than arbitrary, does include the duties and responsibilities which are common to most machine shop supervisors:

1. Getting the right man on the right job at the right time.
2. Using tools and materials as economically as possible.
3. Preventing conditions that might cause accidents.
4. Keeping the men satisfied and happy on the job.
5. Adjusting grievances.
6. Maintaining discipline.
7. Keeping records and making reports.
8. Maintaining quality and quantity of repair work.
9. Planning and scheduling repair work.
10. Training men.
11. Requisitioning tools, equipment, and materials.
12. Inspecting and maintaining tools and equipment.
13. Giving orders and directions.
14. Cooperating with others.
15. Checking and inspecting repaired machinery or replacement parts.
16. Settling differences among the men.
17. Promoting team work.

From the extent of the above list it is obvious that the job of a supervisor covers a broad field, and that a detailed study of such a job is not practicable in this limited space. These items are quite general in nature; it is necessary therefore for each machine shop supervisor to carry out a detailed study of his own specific duties and responsibilities, if he expects to understand all phases of his job.

Some CPO's may feel that minor jobs are beneath their dignity and unworthy of their attention. They expect to

prove their true worth on some presumably more important job, and therefore exhibit little interest in current minor jobs. However, a man who does not supervise minor jobs efficiently is unlikely to be given an opportunity to supervise major jobs. Dreaming of the future while neglecting the present never helped anyone to advance.

There is nothing more discouraging to a man than to see a job that he has done thrown on the scrap heap. Such "scrapping of jobs" may be due to insufficient information on the job, to errors in planning, or to the supervisor's failure to give his men detailed directions. Whatever the reason may be, the men will feel that their efforts have been wasted. Inasmuch as too frequent occurrences of this nature obviously affect the interest of men, the CPO in charge of a machine shop should try in every way possible to prevent such occurrences. If such occurrences do happen, however, the chief should be able to explain and justify the action taken.

The CPO in charge should take advantage of every opportunity to provide the men with specific information about their jobs. If, for example, a man is making small parts, his interest will be greatly stimulated by the chief telling him what the parts are, and where they are to be used, and explaining the importance of the parts with respect to the entire project. The type of chief who says, "Never mind why; just do as you are told" is rapidly being replaced by the supervisor who recognizes the importance of each man knowing why he is doing a job and the effect of his knowing upon the interest he takes in the work.

One subject which is always of interest to men is their pay. Although the chief does not establish the rates of pay for his men, he does, to a certain extent, determine eligibility for promotion by determining their proficiency in rating. Therefore, the chief is in a position to eliminate causes of dissatisfaction relative to rates by dealing fairly with each person and pointing out to the individual the habits and behaviors which affect his efficiency.

People are interested in jobs from which they derive a feeling of accomplishment. They have, to a certain degree,

a desire to construct something, which prompts them to build with their minds as well as with their hands.

A man's interest in his job can be increased if he is given some responsibility. The job need not necessarily be changed. All that may be required is to cause the man to feel that the chief is depending upon him to get the job out efficiently and on schedule. This should be especially true on routine work which does not normally create a feeling of responsibility.

When a man is not interested in his work, it is often because there is little that he knows how to do. The chief can improve the man's interest in his job by training him and thereby expanding his capabilities.

Jobs often acquire a kind of social status quite apart from their monetary return. In every shop there are jobs which have acquired prestige due to any one of a number of conditions, such as specific skills, special technical knowledge, special hazard involved, traditions built up around the job. Cleanliness or neatness of the job may contribute to the social prestige, but usually it must be combined with other conditions to make it really function as an interest factor. The effect of this social prestige is to stimulate the person assigned to the point that he feels he has been promoted. Assignments to these jobs are seldom made as a result of "pull" and for this reason fellow workers recognize the importance of the assignment. As an interest factor this prestige ranks high.

The same is true of men who are given jobs that are special because of priority or difficult conditions calling for extra effort and ability. The mere fact of being chosen, picked out from the crowd as it were, is a distinction that will spur a man on. Because of the extra amount of interest and pride awakened by his being selected, he will be able to do that which he would ordinarily regard as impossible.

Everyone wants to feel that his efforts are appreciated; otherwise he very quickly loses interest in his job. A Chief Petty Officer can fully understand the value of judicious commendation if he analyzes his own reactions toward his present and former officers. Unless he is an unusual type of

person, obviously he would rather work for an officer who recognizes his good work, criticizes his bad work, and helps him correct his errors, than for one who speaks to him only of his faults.

A chief should utilize all possible interest factors. He should study each of his men and use those factors which seem to obtain the best results according to individual characteristics. His ability to interest his men in their work is important to him, as it has a part in determining his success or failure as a supervisor. His proficiency in rating depends in part on the quality and quantity of work his men produce, which in turn reflect the interest and morale of the men in their work.

Cooperation

Cooperation has been defined as "the act of working together willingly and intelligently to achieve a common purpose!" It is most difficult for any man to work alone. His work or job assignments, his observance of regulations, his work ability and capacity, all bear a relationship to other people and are integrated with one another to accomplish an over-all plan and thus reach an established objective. In the Navy, it is the responsibility of a Chief Petty Officer to develop good will among his men, thus leading them, through cooperative effort, to a desired end.

The development of cooperation requires a thorough understanding of certain fundamentals of supervision. One must recognize that the prime purpose of obtaining cooperation is to get out the work. The supervisor must also develop this understanding among his men, in order that they may be ready to cooperate with others. The men should understand that they are working with the CPO, not for him.

There are times when a chief must, in the best interests of operating efficiency, do a job the other fellow's way. If by so doing he will add to the betterment of the organization as a whole, then personal feelings must be disregarded. This is true because achieving a common purpose in the most practical manner contributes to the welfare of all. This is one form of cooperation.

A supervisor seldom uses all the authority which his position provides. To effect the greatest amount of cooperation from his men he must learn to use this authority reservedly. Cooperation obtained without the show of authority is an indication of real leadership.

We must learn that individual and group attitudes play a large part in promoting good will. In winning the cooperation of men, the chief must show by word and action that their interests are his interests.

The attitude of the man toward the CPO in charge frequently reflects the attitude of the chief toward his division officer. If the CPO displays a cooperative attitude, men will respond accordingly. Honesty and impartiality, supported by a thorough knowledge of the work and an understanding of human nature, are important factors in strengthening attitudes. "Know your men" is sound advice for any leading petty officer. Successful supervisors are usually well-posted on personnel matters which affect their men.

Little courtesies and considerations are the seeds from which true loyalty grows, and loyalty promotes cooperation. The showing of courtesy and respect toward men is a surefire way of winning their cooperation.

Clear thinking and careful planning always help to promote good will and loyalty among men. A chief who always knows where he is going and how he is going to get there is quickly recognized as a leader. A job carefully planned stimulates cooperation on the part of the man. Every man wants to follow a leader who knows what he is about. Careful planning will aid in strengthening the CPO's position in this respect. Like loyalty, good planning contributes a great deal toward building satisfactory relationships.

Friction and jealousy sometimes arise among petty officers because of the overlapping of their functions. Therefore, a clear understanding of the boundaries of authority and responsibility should be set if the desired ends are to be reached. When one feels that the other is encroaching upon his functions or is attempting to usurp certain authorities, it is well

to reach an immediate understanding as to the precise jurisdiction of both. If possible, it is best to reach an understanding between one another before appealing to higher authority. Misunderstanding often arises when top supervision becomes careless in delegating authority and responsibility to subordinates. Obviously, this indicates a lack of executive ability.

Adverse criticism of one CPO by another creates antagonism and tends to demoralize the whole working force. If criticism is offered, it should be constructive and tactful. It is far better to talk to the other fellow and not about him. Prior to offering criticism we should analyze the situation carefully to determine the facts. If we do this, we will often find that the basis of our criticism is unfounded.

Certain petty officers, on occasion, try to center attention on themselves at the expense of others. In so doing, they are obviously looking out for themselves and their unit, but fail to recognize that all petty officers are part of the organization. The chief's principal concern is the over-all efficiency of the division.

The chief should be receptive to the suggestions and requests of others and be ready and willing to discuss ways and means that might improve the organization as a whole. Experienced chiefs should encourage younger petty officers to use their initiative and to offer suggestions. If a chief is known to be approachable on matters concerning supervision, he obviously has the entire force working with him. However, if he is not approachable, he works alone and consequently suffers the loss of many wise suggestions as well as much valuable guidance.

It is a serious mistake for anyone to refuse to accept the blame for his own errors. Any attempt to shift such responsibility merely complicates the situation by creating distrust and animosity in the minds of others.

We must always remember that cooperation requires the efforts of at least two individuals. It cannot be effective if it is entered into by one person alone. Make sure that the side from which you are working is doing its part.

TRAINING SHOP PERSONNEL

The military training of the shop personnel (training within the framework of the shipboard training program) is only one aspect of the duties of a CPO. It is covered in the military qualifications that apply to all ratings, and will not be discussed here. Emphasis in this chapter is on the chief's responsibility for training his men in machine shop procedures.

If the CPO in charge of a machine shop has a well-planned program for introducing new men to the work in the shop, he has taken a most constructive step toward building shop morale. One of the best stimulants for the development of high morale among new men is to have them realize that their chief appreciates their feeling of strangeness and is aware of their desire to make good. There is often a gap between the point at which a new man is assigned and the time at which he has developed into a satisfied worker. Proper introduction to the new work bridges this gap, turning the ill-at-ease new man into a confident and interested workman. Since the chief functions in a "line" capacity, he is responsible for the introduction of the new man into the working area and for developing him into a satisfied, well-balanced worker in his work unit. During the early employment period, many of the things told to the new man "go in one ear and out the other," for his interest is centered on getting to the job, rather than on what he is told about the job. The CPO will find it a profitable procedure to review with each new man such matters as his rate, duties, drills, liberty, leave regulations, and other similar shipboard policies. This initial introduction for new men need not take more than 15 or 20 minutes. The chief should be sincerely interested in getting acquainted with the new man and reviewing with him, or providing, essential information about the department and its work. His initial contact should be made primarily to win the man's confidence. The chief may later turn the new man over to a qualified petty officer who is capable of

completing the introduction process and the early training necessary. In most cases, considerable information can be given to the new man by an experienced petty officer selected by the chief to complete the introductory routine.

In carrying out his responsibility for introducing the new worker to the job, the CPO must do a certain amount of planning if the instructions necessary for the proper indoctrination of the new worker are to be carried out effectively.

At this point it may be well to indicate one fundamental difference between the work of a supervisor and that of his men. The men work with machines and materials, while the supervisor works through people to produce the desired results with the machines and materials. The machines may be operating perfectly and the materials may be of the best quality, but unless the men who handle them are properly instructed, adjusted to their work, and cognizant of their place in the organization and of the policies of the department, they will not be satisfied workers. The chief is responsible for developing high morale in each man in his shop.

The first step in this process is attained by properly indoctrinating each new man at the time of his entrance into the work area. There are three general areas of indoctrination:

1. Those dealing with facts, such as the shipboard rules and regulations.
2. Those dealing with the men's attitudes or feelings, their confidence in the organization, pride in the job, and respect for their fellow workers.
3. Those dealing with skills, safe working habits, and quality of work.

To aid in developing men for greater responsibilities is everyone's job. Each person not only must be receptive to that which helps to develop himself, but must also help to develop those who assist him in his work. However, on the Chief Petty Officer in charge of a machine shop falls the direct responsibility to see that all his subordinate petty

officers understand their work and its relation to the function of the machine shop so well that they automatically teach those who assist them.

QUIZ

1. Why is it good practice to assign each rated man his own stowage drawer or tool box, in which he can keep the tools he ordinarily uses?
2. How frequently must you take action to prevent rust, in a shipboard machine shop?
3. Why are cleanliness and order important in a shop?
4. What kind of tools and equipment require custody cards?
5. In making an inventory of tools and equipment, you will need to use a complete listing of equipment, accessories, tools, and spare parts which have been furnished to the machine shop. Where will you find such a listing?
6. When a power-driven tool is being repaired or adjusted, the power supply should be shut off. What other safety precaution is necessary in this situation?
7. What source would you use to find the most detailed description of the operation, adjustment, and care of a particular piece of shop machinery?
8. Where can you find a list of filing numbers and their subject matter references, for use in locating blueprints?
9. In the blueprint filing system, how is the subject-matter group indicated?
10. What priority is assigned to most of the job orders which come into a shop?
11. What general rule should you follow in selecting a metal to use as a substitute for the specified metal?
12. What is the best way for you to learn how to make accurate estimates of the time required for repair jobs?
13. If a repair job requires the cooperation of several shops, the chief in charge of the machine shop will need estimates of the time required for the other shops to complete their part of the work. Who should make these estimates?
14. At what stage in the accomplishment of a repair job should the chief in charge of the machine shop obtain time estimates from other shops, for their share of the work?

15. When estimating time for repairs to a high-speed rotating assembly, why must you allow time for balancing the unit even if it is properly balanced before it comes into your shop?

16. Why is it a good idea for the chief in charge of a machine shop to assign new jobs to relatively inexperienced men, when the general workload of the shop is light?

17. Before a repair job leaves the machine shop, who is responsible for checking to see that the parts have been correctly formed and accurately dimensioned?

18. What duties does a chief have on the basis of the fact that he is part of the ship's administrative organization?

19. Why should the unit "man-hours" be used with caution when you are estimating the length of time required for a repair job?

20. What should the COMPLETED job order show?

CHAPTER 13

DAMAGE CONTROL ORGANIZATION

The design of naval ships provides resistance to damage compatible with other military characteristics. The maintenance of the damage-resistance features of strength, watertight integrity, stability, proper displacement, proper distribution of liquids, and optimum material and personnel readiness before attack is as important for ultimate survival as are damage-control measures after damage is sustained. In spite of all precautions and preparations that can be made before damage, however, the survival of the ship will often depend upon prompt and correct control measures after damage. It is necessary, therefore, to train the entire ship's company for any eventuality.

In order to ensure proper training and to provide prompt and correct control in event of casualties, a damage control organization must be set up and kept active. In most cases the Chief or First Class Machinery Repairman will be included in the damage control organization during drills and actual emergencies. In this organization, as in any other organization, the Chief or First Class must understand the purpose and function of the organization in order to fully carry out his duties as a leading petty officer. He also may be called upon to instruct, supervise, and train nonrated men in basic damage control functions and procedures.

FUNDAMENTALS OF THE ORGANIZATION

The basic meaning of organization is the combining of many parts into a workable system. This system is the backbone of damage control. Your success as a leading petty officer in the organization will depend on your complete understanding and ability to help fit these parts together, then to make them work. In order to do this, you should have a good fundamental knowledge of the damage control organization as it works in battle and in normal day-by-day routine.

The routine business and operation of the ship are controlled by the permanent ADMINISTRATIVE ORGANIZATION of the ship, an organization which, as you know, consists of the various departments of the ship. In most cases a Machinery Repairman is assigned to one of the machine shops of the repair department.

In order to make the ship ready for battle conditions or major emergencies, another organization is set up. This is known as the BATTLE ORGANIZATION, and includes the damage control organization. Since relatively minor periods of a ship's total time will be spent under battle conditions, this organization is more or less temporary. Do not let this word "temporary" mislead you, however, for the battle organization is a vital one and it must be kept up to the highest possible standards. Because of the relatively short periods of time that the ship's crew is exercised on stations under the battle organization, it is imperative that an all-out effort be made to perfect the functioning of the organization and the training of personnel. When all battle stations are "manned and ready" during battle conditions, a strict and efficient organization must be ready to function.

The damage control organization under battle conditions is also of a temporary nature, as it will include personnel that have only temporary or collateral duties in damage control. The membership of the group responsible to the damage control assistant under battle and normal conditions varies. For example, in battle condition, a repair station on

a ship will be made up of many different ratings. These men, as members of a repair party, will serve under the Damage Control Assistant. However, only the DC, FP, and ME ratings will serve under him in normal ship's routine, the other members of the repair party serving under their respective division heads.

OBJECTIVES OF DAMAGE CONTROL

The three basic objectives of shipboard damage control are: (1) To take all practical preliminary measures before damage occurs, such as maintenance of watertight integrity and fumetight integrity, maintaining reserve buoyancy and stability, removal of fire hazards, and upkeep and distribution of emergency equipment; (2) to minimize and localize damage, when it does occur, by such measures as control of flooding, preservation of stability and buoyancy, fire fighting, and first-aid treatment of personnel; and (3) to accomplish emergency repairs or restorations as quickly as possible after the occurrence of damage, by such measures as supplying casualty power, regaining a safe margin of stability and buoyancy, replacing essential structure, and manning essential equipment.

The ship's ability to inflict punishment upon or destroy the enemy or to perform any other assigned mission may well depend upon the effectiveness of damage control. Damage control then must be considered as an offensive, as well as a defensive, function.

Damage control is concerned not only with battle damage but also with nonbattle damage, such as fire, collision, grounding, or explosion. It may be necessary in port as well as at sea, and may involve the use of personnel and facilities of an undamaged ship.

KNOWLEDGE NECESSARY FOR DAMAGE CONTROL

Damage control requires a detailed knowledge of ship construction, characteristics, compartmentation, stability, and those appurtenances placed on board a ship to prevent or

control damage should a ship be endangered. Basically, the control of damage depends upon the ability of personnel to take prompt corrective action, using material which is available. Having a thorough knowledge of the ship will enable personnel to determine readily the corrective action to be taken.

First, you should know the fundamentals of the various methods and procedures used to prevent damage to a ship and to protect its personnel, to control any form of damage or casualty that may occur. Damage control, in its full meaning, is quite extensive and includes a wide field which covers many subjects and activities. Some of the major divisions are:

1. Stability and buoyancy.
   Watertight integrity.
   Ship construction and compartmentation.
   Hull strength.
   Piping, electrical, and other systems.
2. Fire fighting.
   Flooding control.
   Investigation of damage.
   Emergency repairs.
   Shallow-water diving.
3. Operation of damage control equipment.
   Damage control communications.
   Casualty power and lighting.
4. Damage control safety precautions.
   First aid.
   Chemical warfare.
   Radiological warfare.
   Biological warfare.
5. Preventive maintenance.
   Allowance of damage control equipment.
   Allowance of damage control material and spare parts.
   Material inspections and records.

6. Damage control organization and training.
   Damage control drills and battle problems.
   Damage control competition and inspection.

The ship's damage control library consists of books, pamphlets, and publications which contain information or instructions necessary for the practical application of the theory of damage and casualty control. More detailed information on the list of publications may be obtained from the ship's damage control officers or by referring to chapter 88 (article 88–505) of BuShips *Manual*.

Valuable information in regard to damage control may be obtained from chapter 88 of BuShips *Manual;* chapter 93 gives information and instructions on fire fighting.

APPLICATION OF DAMAGE CONTROL PRINCIPLES

In accordance with various directives from higher authority, the damage control officer and the damage control organization should impress upon all personnel the necessity for obtaining the highest degree of efficiency in the control of damage through the thorough understanding and application of damage control principles.

All leading petty officers and men of the damage control organization should obtain a working knowledge of the ability of the ship to resist damage and remain afloat. This knowledge is best obtained by a thorough study of the ship and its systems, and by the study of methods successfully used and of mistakes made by other ships in combating damage.

Damage Control Books

Damage control books are restricted publications issued by BuShips to individual ships which were originally constructed as naval vessels. They contain material information in the form of text, tables, and diagrams concerning the construction, facilities, and characteristics of the ship. They also give information on complicated piping and electrical systems in connection with damage control.

One of the first requirements of damage control is to know your ship, and for this the damage control book will prove a great aid. A detailed knowledge of the ship is required before the proper damage control procedures or methods can be applied. Since there are many types and classes of ships in the Navy, general damage control procedures and training will have to be specialized for the particular ship in question.

Ship's Organization Book

Every ship maintains a ship's organization book. It is made up under directives usually set down by the type commanders in the Standard Organization Book for ships of a certain class.

In the ship's organization book you will find information and orders for the routine organization and procedures on board ship. Also one will find the organization and procedures in case a special or emergency condition occurs. The latter is made up in the form of bills. Some of these bills are as follows: Cleaning, Maintenance, and Repair Bill, Battle Bill (including various conditions), Fire Bill, Collision Bill, Abandon Ship Bill, Fire and Rescue Bill; Special Sea Detail Bill; Jettison Bill; Scuttle Ship Bill; Salvage Bill; Gas Defense Bill; Radiological Safety Bill; and Darken Ship Bill. There are many other bills; only the most common ones are listed above. It will be noted that some form of damage control is connected with most of the above bills. Therefore, to fully understand the organization of the ship in regard to damage control one must read and understand the ship's organization book.

Watch, Quarter, and Station Bill

Many of the above bills will appear on the Watch, Quarter, and Station Bill. It will be the responsibility of each chief and first class petty officer to see to it that all the men in his gang know their duties and responsibilities in regard to the various bills. The leading petty officer must instruct

new men in the duties of their billets on the Watch, Quarter, and Station Bill.

Damage Control Bills

Damage control operating bills are prepared by all ships whether or not damage control books have been furnished. These bills must be kept current at all times by modifications to suit any late alteration to hull, armament, or machinery, or any changes in complement.

Damage control bills should outline repair procedures and contain instructions for operating the various systems, in conformity with the designated material conditions of closure, so that the objectives of damage control will be best obtained. Damage control bills are important in organizing the ship for damage. It is essential that the leading petty officers understand these bills and be familiar with them, since effective training is based on adequate organization.

It will be noted that many of these damage control bills appear in the ship's organization book.

Engineering Casualty Control Book

The Engineering Casualty Control Book is similar to the ship's organization book and the damage control bills in that it gives the organization and procedures in case of casualties or damage. Many of the damage control bills also appear in this book.

Engineering casualty control is concerned with the prevention, minimization, and correction of the effects of operational and battle casualties to the machinery, electrical, and piping installations. Its mission is the maintenance of all engineering services in a state of maximum reliability under all conditions of operation. The first objective under this mission is the effective maintenance of propulsion, auxiliary and electric power, lighting, interior and exterior communications, fire control, electronic services, ship control, firemain supply; and miscellaneous services, such as heating, air conditioning, and ship's service compressed air. Failure to pro-

vide all normal services will affect the ship's ability to function effectively as a fighting unit, either directly by reducing her mobility, or her offensive and defensive power (including the ability to control fire, flooding, and hull and armament damage), or indirectly by reducing habitability and thereby reducing morale and efficiency. The second objective is the minimization of personnel injuries and secondary damage to vital machinery, since minimizing these factors contributes in a large degree to the successful and continued accomplishment of the first objective.

ORGANIZATION FOR CONTROL OF DAMAGE

Although naval ships may be large or small and of different types, the basic principle for the damage control organization during battle conditions remains more or less standardized. Some organizations are larger and more elaborate than others but they all function on the same fundamental principles.

A standard type damage control organization, suitable for large ships but to be followed by all ships as closely as practical, includes the following:

1. A damage control station.
2. Repair 1 (deck, or topside, repair party) 1F, forward; 1A, aft; 1B, amidship.
   Repair 2 (forward below decks repair station).
   Repair 3 (after below deck repair party).
   Repair 4 (amidships below deck repair party).
   Repair 5 (main propulsion repair party).
   Repair 6 (ordnance repair party) 6F, forward; 6A, aft.
3. (On Carriers).
   Repair 7 (gasoline repair party).
   Repair 8 (flight deck repair party).

These repair parties each have a specifically located headquarters and are further subdivided into patrols, units, or secondary groups. This permits dispersal of personnel and a wide coverage of the assigned areas.

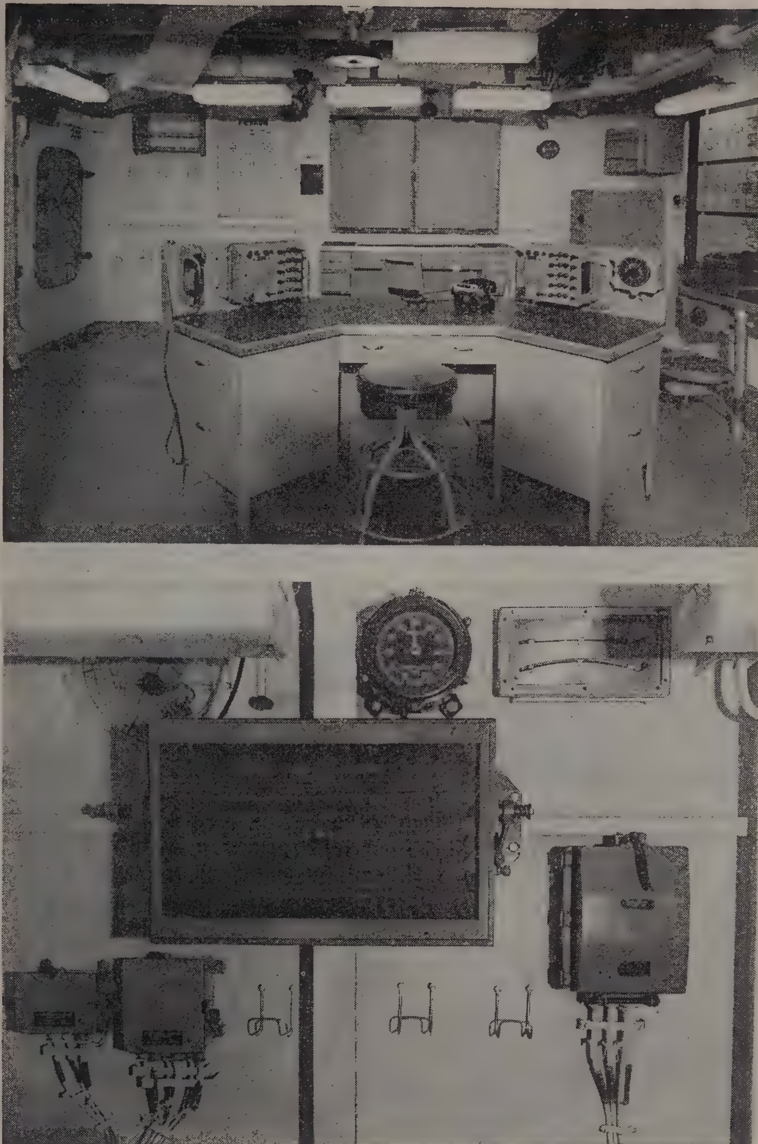


Figure 13–1.—Damage Control Central Station.

Damage Control Central Station

The Damage Control Central Station is the battle station of the Damage Control Assistant. It will be found in a central location and as well protected as possible. On a large ship, this station is manned by a group including a stability control officer, a casualty board operator, and a damage analyst. One will also find representatives of fuel oil, electrical, and ordnance groups; and telephone talkers who have the required background and are trained to receive, deliver, and record messages. Figure 13–1 shows a compartment used by the personnel of the Damage Control Central Station.

In any ship's damage control organization, arrangements are made for a designated repair station to take charge of damage control activities. Should this central station be destroyed or rendered unable to retain control, other repair stations, in designated order, take over these same functions. Provisions are also made for passing the control of each repair party and its operation down through the officers, petty officers, and nonrated men, so that at no time will any group be leaderless.

The purpose of Damage Control Central is to collect and compare reports from the various repair parties in order to determine the condition of the ship and the action that should be taken. The commanding officer is kept posted on the condition of the ship and on important corrective measures taken. Repair party reports are carefully checked so that immediate action can be taken to isolate damaged systems, and to make emergency repairs in the most logical manner. Graphic records of the damage are made on various damage control diagrams or status boards, as the reports are received. For example, as reports come in concerning flooding they are marked up on a status board, which contains a record of liquid distribution before damage. With this information, the stability and buoyancy of the ship can be estimated, and the necessary corrective measures can be determined. Orders can then be sent for the required action.

A ship is a very complex structure and it would be practically impossible for an individual to learn all the details of the various systems, such as piping and ventilation, built into it. There must be some means of facilitating the locating of any part or section of these systems, and the section of the ship. This is especially true during an emergency. It is accomplished by means of diagrams that are kept at Damage Control Central and at the various repair party stations.

The Repair Party

The repair party is the Damage Control Assistant's representative at the scene of the casualty or damage. At his battle station, the Damage Control Assistant is the nerve center and directing force of the entire damage control organization. (See fig. 13–2.)

The orders and information given by the damage control officer cannot be all-inclusive, however, because many of his decisions must be delayed pending a complete and reliable estimate and analysis of the extent of damage, based on the receipt of accurate reports. These reports to a large extent come from the repair party in the affected area. The overall effectiveness of the damage control organization is directly proportional to the effectiveness of the links in its chain—namely, the individual repair parties.

In distributing the available personnel to a repair station (see fig. 13–3), one will find that an engineering repair party will consist largely of Machinist's Mates, Machinery Repairmen, Boilermen, Enginemen, and Firemen.

All repair parties will have EM or IC ratings, whose duties, among other things, are to make emergency electrical repairs on the scene, to direct the establishment of casualty-power connections, to test and locate damaged circuits, to restore communication circuits or provide emergency means of communication, to provide the damage control repair or central station with information concerning the extent of electrical damage, and to aid and advise men working around electrical damage to protect them from electrical shock.

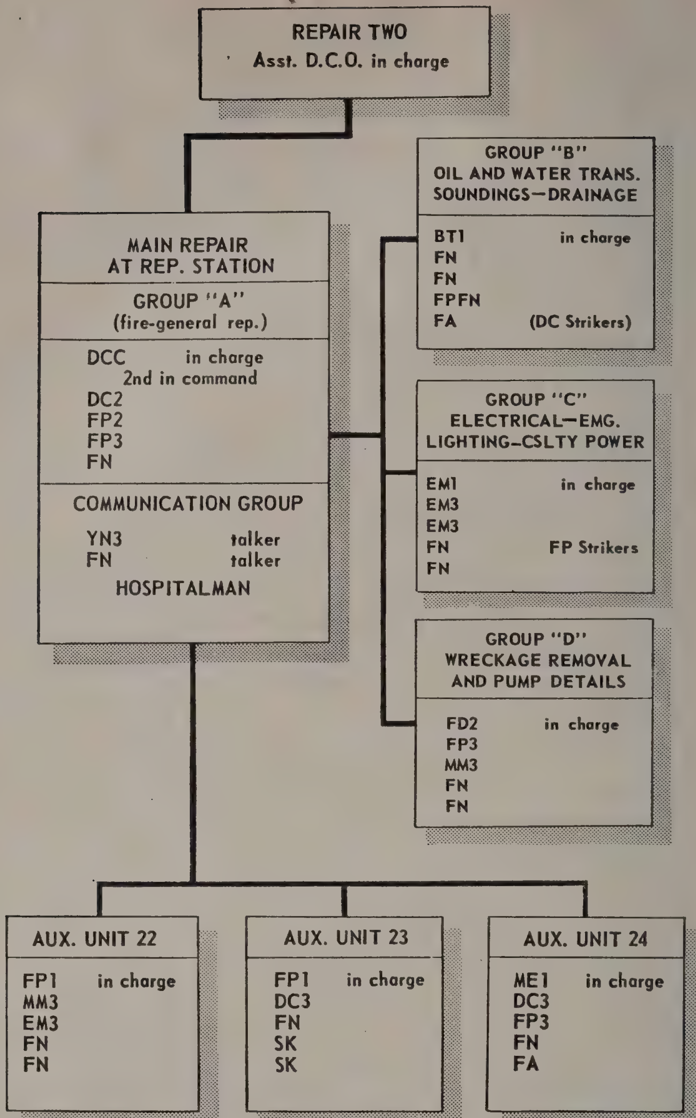


Figure 13–2.—A repair party complement (large ship).

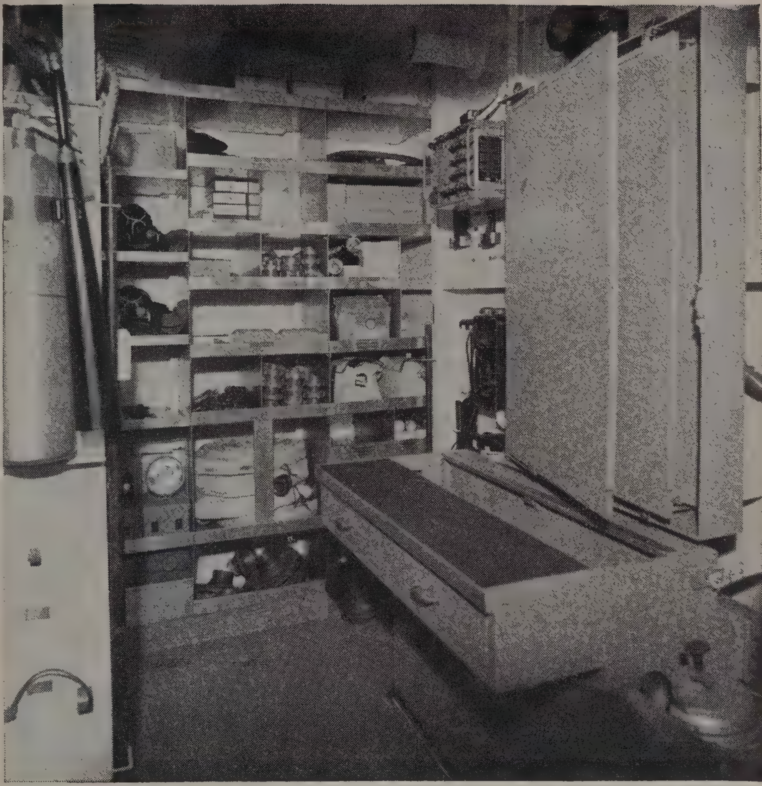


Figure 13–3.—A repair party station.

Repair parties assigned to areas in which magazines are located should properly have Gunner's Mates as part of their personnel. Storekeepers should be assigned to repair parties that have storerooms located in their areas.

The number and the ratings of men assigned to a repair party or station are determined by: (1) the locale of the station, (2) the portion of the ship assigned to that party, and (3) the total number of men available for all stations.

Many repair parties have auxiliary repair lockers at strategic locations in their assigned area to supplement the repair station's equipment. Figure 13–4 illustrates such a repair locker.

Figure 13–4.—A repair locker.

Each repair station will have an Officer in Charge, who may in some cases be a chief petty officer. The second in charge of a repair party is in most cases a chief petty officer who is qualified in damage control and is capable of taking over the supervision of the repair party.

A set of operating instructions should be posted at each repair station. In general, these instructions will include the following:

1. Purpose of the repair party.
2. Specific assignments of space for which that party is responsible.
3. Instructions for assignment and stationing of personnel.
4. Methods and procedures of communications.
5. Instructions for handling machinery or equipment such as anchor windlass, steering gear, sprinkler systems, etc.
6. Functions of gas defense and the decontamination of personnel.
7. Sequence of command and the procedure therewith.
8. List of basic damage control drills.
9. An inventory list of all damage control equipment and gear provided for the repair party.

Organization for Fire Fighting

Repair parties provide the only personnel immediately available to fight fires during action. Other personnel, gun crews for example, must leave their primary duty should they have to fight a fire. It is essential that a plan of action embodying a systematic procedure for fighting fires be established. Loss of valuable time will be the inevitable result if the decision as to the method to be used in fighting a fire is not made immediately. Large repair parties may be divided into fire-fighting groups. In small ships, an entire repair party might be required to make up a complete fire-fighting group or "team." Where possible, at least two such groups should be organized from any one repair party. These groups should be trained so that any member can quickly undertake any of the detailed duties, as circumstances warrant.

Members of repair parties will generally be assigned to fire-fighting positions as follows:

1. Hose men (number determined by the size of hose).

2. Plug man.
3. Access men.
4. Foam generator operator.
5. Foam supply men.
6. Portable CO_2 men.
7. Oxygen breathing apparatus and asbestos suit men.
8. Tenders for men wearing breathing apparatus and asbestos suits.
9. Ventilation detail.

In smaller fire-fighting groups, one individual must necessarily perform more than one of the detailed duties. This should be provided for when organizing the group. A fire-fighting group consisting of as few as four men can be effective. The senior rated man should be designated as the group leader. His first duty is to get to the fire quickly, investigate and determine its nature, and supervise his team in fighting the fire. He must decide if additional or different equipment is required; also, he must decide on the number of personnel required for fighting the fire. The analysis he makes must be in accord with the principles that are set forth in chapter 93, BuShips *Manual*, and taught at the Navy fire-fighting schools.

Although fire fighting is one of the most important functions, the repair parties have other duties for which they must organize and train. Some of these are chemical warfare defense, radiological defense, biological defense, investigation of damage, shoring, etc.

DAMAGE CONTROL COMMUNICATIONS

Damage control communications is of vital importance to the damage control organization. Without adequate means or proper procedures of communications between the different units of the damage control organization, the whole organization would break down and fail in its primary functions. Therefore, proper organization and procedures for damage control communications cannot be overemphasized.

It is impractical to cover in detail all types of ships in describing communication systems. Figure 13–5 covers only the IC systems found on large combatant ships. A general knowledge of these systems, however, will promote better understanding of the other systems in use in smaller ships.

The normal means of damage control communications abroad large ships are:

1. Battle telephone circuits (sound-powered).
2. Interstation 2-way systems (4MC intercoms).
3. Ship's service telephones.

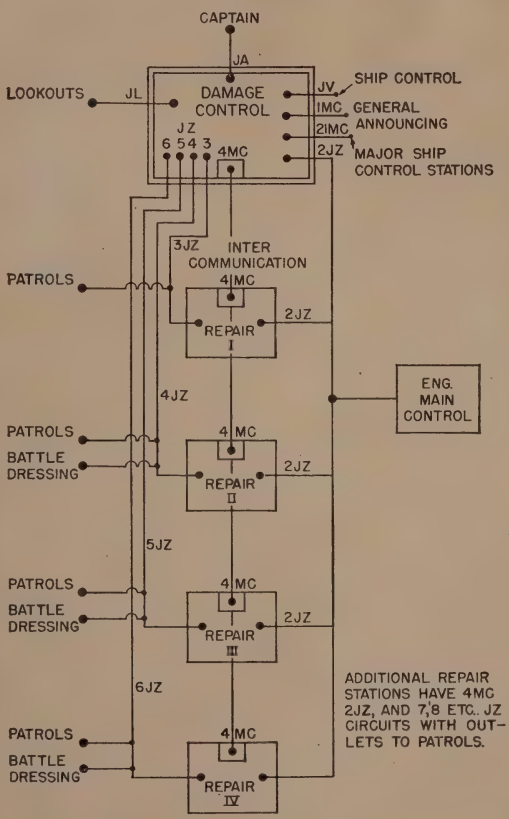


Figure 13–5.—A damage control interior communication plan.

4. Ship's loud-speaker system (1MC general announcing).
5. Voice tubes (where installed.)
6. Messengers.

Battle Telephone Systems

The battle telephone systems are sound-powered circuits. They require no outside source of electric power. The transmitter of the sound-powered telephone is an instrument designed to transform sound waves into electrical energy. The receivers are capable of converting this electrical energy into similar sound waves. Outlets for sound-powered battle telephones are located at numerous critical locations throughout the ship.

The normal damage control sound-powered circuits are:

2JZ Damage and stability control.
3JZ Main deck repair 1.
4JZ Forward repair 2.
5JZ After repair 3.
6JZ Admidships repair 4.
7JZ Main propulsion repair 5.
8JZ Flight deck repair (carriers only) 8.
9JZ Magazine sprinkling and ordnance repair—6F, forward.
10JZ Magazine sprinkling and ordnance repair—6A, aft.
11JZ Superstructure repair (battleships only).
3JG Aircraft service (carriers only).
6JG Aviation ordnance (carriers only).
7JG Conflagration control (carriers only).
JA Captain's battle circuit.
1JV Maneuvering, docking, and catapult control.
2JV Engineer's circuit (engines).
3JV Engineer's circuit (boilers).
4JV Engineer's circuit (fuel and stability).
5JV Engineer's circuit (electrical).
JL Lookouts (surface and sky).

A schematic arrangement of the damage control telephone systems on a large ship is shown in figure 13–5.

THE JZ SOUND-POWERED CIRCUITS.—The 2JZ sound-powered circuit is common to the damage control central station and all repair parties. (See fig. 13–5.)

The 3, 4, 5, 6, and even 7 JZ circuits are individual repair party circuits, connecting each repair party station with its auxiliary station and patrol areas. Each of these repair party circuits has an outlet in the Damage Control Central Station, through a selector switch or individual jackboxes, or both. The latter is preferable and permits the manning of each circuit by individual talkers.

Where individual manning is done, the 2JZ circuit is preferably used as an outgoing circuit from the Damage Control Central Station, carrying information and orders from the Damage Control Assistant to the various repair party stations. Each individual repair party circuit (3, 4, 5, 6, and 7JZ) thus becomes an incoming circuit into the Damage Control Central Station. This automatically makes the Damage Control Assistant, through any of his talkers, either an "information or an action addressee" on any messages carried over any individual repair party circuit.

In smaller ships where only a single circuit may be available, both incoming and outgoing messages must be handled over it.

EMERGENCY COMMUNICATION.—On ships having a minimum length of 200 ft., circuit X40J is installed for the purposes of providing emergency communication between the open bridge, main engine control, damage control, and the steering gear room. Permanent risers are installed port and starboard to the vital spaces. Portable cables fitted with jackboxes and plugs are provided for interconnecting the riser jackboxes with each other and to telephone headsets. The wire provided is a special portable wire that may be passed through watertight doors and hatches without destroying the watertight integrity.

AUXILIARY CIRCUITS.—Most ships have auxiliary circuits which are, for all practical purposes, duplicates of the primary circuits. These circuits serve the same stations as are served by vital primary circuits.

String Type Circuits.—String type circuits are a third sound-powered circuit which are installed in stations not especially vital to ship operation. They are installed in such locations as between the upper and lower handling rooms of 5-in. mounts, turret stations, topside radio, radar and direction finder stations. Although these circuits are not normally used for damage control purposes, their existence in stations or sections of the ship not served by damage control circuits must not be forgotten, as in emergencies they may be tied in to primary circuits in order to extend communications to a remote section.

Other Means of Communication

Intercommunicating Units.—Systems of recent design employ the intercommunicating units (circuit 4MC) on the damage control announcing system. These units provide a dependable and fast 2-way transmission of damage control orders and information between the Damage Control Central Station and each repair station. Also, a 1-way communication is provided from each repair station to each repair party area served by that station by utilizing satellite reproducers.

Ship's Service Telephones.—On many ships these are available for use where they are installed at or near repair stations. Too much reliance should not be placed on them as they are not part of a rugged battle system and may go out of commission early in action.

Ship's General Announcing System.—This system (1MC) is a means of communication, but so many stations other than damage control are affected that it is not desirable to use it unless all other methods fail. It should be reserved for warnings or for vital information that affects the entire ship's company.

Messenger Service.—The damage control organization should provide for messengers. Repair party personnel should be trained as messengers for relaying orders and information. A written message is always more reliable

than an oral message. However, messengers should be trained to carry oral orders without error.

Control of Telephone Circuits

Wherever possible, one circuit should not be used for both an outgoing and an incoming line, as the resulting confusion will greatly increase the difficulties of getting information through correctly and speedily.

It is imperative that control of a telephone circuit be established by the major controlling station so that an orderly flow of communication may be obtained. The circuit must never be allowed to get out of control as a result of "cross-talk" caused by more than one station assuming that it has the priority message. The controlling station must be able to clear the circuit immediately and establish a priority for messages whenever the need arises.

Succession of Repair Stations to Control.—The chain of succession of repair party stations to main control must be well established as a permanent plan in the event that the Damage Control Central Station is destroyed, or temporarily put out of commission.

By not answering to communication, Damage Control Central may simulate being out of commission. This provides a test of the organization and procedures of the station designated to assume command; and the efficiency and speed with which repair parties take over control can be noted. The next station in the chain of control, by testing at regular intervals, should soon discover that Damage Control Central is "out," if they can communicate with other repair stations and cannot contact Damage Control Central by any means of rapid communication. They should then take over the control and notify all other repair stations, the commanding officer, and main engine control that they are doing so. This information must be positive and there must be no doubt who has control for damage. After the second station has taken control, an investigation party should be sent to Damage Control Central Station. This procedure

should be followed until all stations have succeeded to control for damages and have exercised this control properly. Damage Control Central can always regain control by saying "Damage Control Central taking over control," and receiving proper acknowledgements.

This drill should emphasize the necessity for keeping written logs of all information and orders given by Damage Control Central whether it applies to the specific station or not. In the event a repair station succeeds to control for damage, it must know what casualties all other stations are handling in order to assume control intelligently.

Damage Control Communication Bill.—The organizational details of damage control communications should be written up in the form of a bill so that they will be readily understood and followed by all damage control personnel. These details should include such items as: (1) succession to main control, (2) primary circuits and stations to be manned, (3) procedure for shifting to secondary circuit in case of failure of the primary circuits, (4) procedure for clearing damaged circuits by means of cut-out switches, (5) rigging of emergency communications, (6) policies regarding priority of messages and what information should be sent on each telephone circuit, (7) standard phrases and practices to be used, (8) rules for talkers, care of telephones, and (9) other items suitable for the control of damage for the ship concerned.

It is also recommended that this bill should list alphabetically the ship's interior communication circuits, and the location of their outlets. Then, in addition, a list can be made of each station or compartment, showing the various circuit outlets installed at these stations. This will greatly facilitate setting up emergency, auxiliary, or extended communications.

Telephone Control Stations.—At these stations are located the action cut-out switches for clearing the battle telephone systems in case of damage or short circuits. On large ships, this isolation may be accomplished by means of

action cut-out switches found in the controlling station of each circuit or on the main telephone switchboard in interior communication rooms. In these installations both stations may take the action necessary to isolate short-circuited portions of a circuit, thus restoring the remainder of the circuit to use. These action cut-out switches whenever provided are the best protection against total and continued lack of communication if their operation and importance are fully recognized. The damage control communication bill and organization for use of alternate circuits, in the event of damage entailing loss of communication on primary circuits, will recognize the importance of action cut-out switches and their locations. The talker that has this cut-out switch at his station will have control of the entire battle telephone circuit.

Vulnerability of Damage Control Communications.—The vulnerability of the communications on which damage control organization depends for its reports, order, and information has been demonstrated in action. Although improvements have been made in this respect, the danger of organizational failure must be guarded against. The various methods of communication between vital parts of the ship should be thoroughly understood so that, if the line of communication normally used becomes damaged (and cannot be cleared up), available alternative lines of communication can be readily placed in operation. This procedure must be clearly understood by all damage control telephone talkers or, otherwise, confusion will result and the damage control organization will break down. Frequent drills should be held, where circuits are actually shorted without warning, to test the flexibility of damage control communications. All lines of communications should be tested periodically by IC maintenance personnel.

Damage Control Reports During Action

Reports by Patrol or Investigators.—Patrols, investigators, or others should make their reports to the Officer

in Charge of their respective repair party station; he will coordinate the information and pass it along to the Damage Control Central Station. Portable sound-powered telephones are invaluable for maintaining communication between the scene of a casualty and the repair party station.

Reports From Repair Parties.—The most dependable source of information will be the repair parties investigating at the scene of damage. Repair party personnel should be trained to make prompt, accurate reports to the Damage Control Central Station.

It will be necessary to make several reports when damage is inflicted. The initial report should contain the following information:

1. Nature of damage (Class B fire, bomb hole, ruptured firemain, etc.).
2. Location of damage (deck, frame number, athwartship position relative to centerline—i. e., port, starboard, or centerline—and compartment number).
3. Extent of damage (flooding—approximate gpm; fire—smoke or toxic gases present).
4. Measures being taken to combat damage (investigation still in progress; fire fighting—number of hoses, size of hose, type of extinguishing agent, and method of application; dewatering compartment—number and types of pumps being used).
5. Assistance required.

This report must be made as soon as possible and any information which cannot be contained in the initial report should be made in subsequent reports. These reports are made to Damage Control Central for the primary purpose of keeping the Damage Control Assistant posted, in order that he can recommend such action as will not only assist your repair party but also be best for the over-all safety and stability of the ship.

Examples are given below of typical reports which might be telephoned in to Damage Control Central by the telephone

talker in a repair party fighting a fire in a living compartment aboard ship:

Initial Report:

"Damage Control Central, Repair 2, Class Able Fire, 3d Deck, Frame 80, STBD Side, Compartment A–309–L."

"Two salt-water hose teams attacking fire with high velocity fog and solid stream."

"Unit hose teams are entering surrounding compartments to cool down bulkheads."

Second Report:

"Damage Control Central, Repair 2, Class Able Fire, 3d Deck, Frame 80, STBD Side, Compartment A–309–L under control."

"Unit hose teams are cooling down bulkheads in surrounding compartments."

Third Report:

"Damage Control Central, Repair 2, Fire Out, 3d Deck, Frame 80, STBD Side, Compartment A–309–L."

"Flash back hose team has been stationed. Compartment being ventilated. Dewatering of compartment in progress, using one P–500."

"Damage sustained—20 bunks burned; no personnel casualties."

Fourth Report:

"Damage Control Central, Repair 2, Secured Flash Back Hose Team from Compartment A–309–L, 3d Deck, Frame 80, STBD Side."

"Completed dewatering compartment."

"Cause of fire not determined."

Reports of Damage Control Central.—The damage control officer must ascertain from the commanding officer what information he desires with regard to extent of damage and corrective measures, how detailed it should be, what circuits it is to be supplied over, and when. The question of "when" involves what the CO wants to know while the action is still in progress, and what information is to be withheld

until after the action is broken off. Key personnel should be indoctrinated in the procedure established. Usually a brief summary and corrective action taken in regard to damage, fires, flooding, buoyancy and stability, speed available, reductions in gunpower, and probable results of the casualty is transmitted to the bridge and relayed to the commanding officer.

Conditions Affecting Reports.—When general quarters is sounded, for drills or before action takes place, the normal reports of stations being "manned and ready", and checking of communication circuits for proper operation are made; periodic checks are made to be certain that all parties are on the line.

When a single hit or casualty occurs, the major part of communications is the flow of information and orders from the repair party concerned and Damage Control Central.

The difficulties in communication become apparent when there are numerous hits or casualties throughout the ship. All the repair parties will be trying to send information to Damage Control Central at once. Communication circuits will become overloaded and jammed unless the proper procedure and control is maintained. Training and frequent drills are invaluable in this respect. A policy of priority of different types of messages should be well established. Messages of vital information or ones that require immediate action of some other damage control unit should be sent first. When these have been transmitted, other important messages or reports should be sent. Routine messages and those of little importance should be held up until all others have been transmitted and lines are free. Usually, these messages or reports are held over until there is a lull period when no action is taking place. The damage control communications bill should give the priorities of reports and information of various types. This should be well understood by damage control communication personnel and by personnel directing damage control activities.

DUTIES OF PETTY OFFICERS IN A DAMAGE CONTROL ORGANIZATION

The Chief or First Class Machinery Repairman, because of his experience in repair work, is a logical candidate for a repair party battle assignment. This assignment is not the same as his permanent one in a machine shop; but because of his mechanical ability, knowledge of tools and equipment, and miscellaneous repair experience he will quickly adapt himself to the various damage control functions. Also, he may have had considerable damage control instruction and experience when he was a Machinery Repairman 3 or 2. When a petty officer, regardless of his rate, is assigned a damage control organization during battle conditions he must be able to perform the required damage control duties. To some it may appear to be a temporary or additional assignment. But it must be remembered that the control of damage is a vital function and may mean the difference between losing or saving a ship.

Know Ship's Damage Control Organization

A Chief or First Class assigned to a repair party as his battle station must understand thoroughly the damage control organization on his ship. If in doubt he should see the Officer in Charge of the repair party or the Damage Control Assistant for the necessary information or instructions. He must understand the organization for damage control and be competent in damage control procedures.

The leading petty officer of a repair party, if so assigned, must be familiar with and review as necessary, the ship's organization book, ship's damage control bills, ship's damage control book, damage control diagrams, BuShips *Manual* (chapters 88 and 93), and other material pertinent to damage control and its organization.

If assigned to a certain repair party he must clearly understand its organization and how its various functions are carried out. Also, he must have a general knowledge of loca-

tion and duties of the other repair parties, including Damage Control Central Station. The knowledge of the various units and of how they work together to form the damage control organization is most important to supervisory personnel.

Make the Organization Function Properly

The best damage control organization is of no practical value if it exists only on paper. Its proper functioning depends upon the officers, chief petty officers, and leading petty officers in the organization. Knowledge, leadership, and training are some of the basic requirements for leading and supervisory personnel in any organization.

Besides the knowledge of fundamentals, the leading petty officer must see to it that the proper organizational procedures are carried out where groups of men are involved in such phases of damage control as fire fighting, flooding control, damage control communications, etc. He should correct and supervise personnel with the aim of obtaining a smooth-running and efficient organization.

Be Able To Take Over Leadership

In the Navy a man is always preparing himself for advancement by studying and becoming proficient in the practical requirements for the next higher rate. The same principle holds true for personnel in a damage control organization. The second senior man should be able to take leading man's job of a partial or of a complete repair party. In a battle engagement the officer or key petty officer may be injured. To prevent confusion or disorganization, the second in charge of a unit or repair party should be able to take over the leadership.

Another condition may come up when the ship is in port. A fire, collision, or casualty may occur when only the duty section is on board. Many of the key personnel of the damage control organization will be away from the ship and it will be the duty of those on board to carry out the proper

procedures of controlling damage or extinguishing fires. In this case good leadership is especially required, because men (not in the damage control organization) will be more or less unfamiliar with the damage control organization and procedures, and will require prompt and positive leadership by petty officers of the damage control organization in order to be effective damage control or fire-fighting units. If this leadership is not provided, general confusion and disorganization may result, with little or no effective corrective measures being taken. Too many men congregating at the scene of casualty may also create confusion. Personnel not needed should be cleared from the scene of action and stationed at a location where they may be promptly called as conditions may require.

Training of Personnel

As a PO or CPO you may be charged with supervision of all or part of a repair party station. Inasmuch as the success of battle repair depends, in part, on knowledge and speed, the element of time does not allow for detailed supervision at the scene of the casualty. For this reason, during routine drill or training periods, one must train men so that it will not be necessary to give detailed supervision when actual casualties or damage occur.

Training of personnel in damage control subjects may be accomplished by methods such as the use of training film, training aids, training mock-ups, and lectures and demonstrations. Men are taught by actual operation and use of all damage control equipment and material. Fundamental drills and complicated battle problems are held. As a leading petty officer assigned to a damage control organization, you may be required, under the supervision of the Damage Control Assistant, to supervise and train men. Much of this training will take place when the ship is drilled at general quarters. As in any "team," training must begin with the individual and should stress fundamentals.

Check-off lists can prove valuable aids. These can be used

to list individual operations in which men are to be trained, as in the following example:

1. Material Conditions of Readiness.
   a. Setting Material Conditions.
   b. When Conditions Are Set.
   c. Setting Material Conditions On:
      (1). Firemain.
      (2). Ventilation.
      (3). Piping and Drainage Systems.
2. Damage Control Equipment.
   a. Pumps.
      (1). P–500.
      (2). Handy Billy.
      (3). Submersible Pumps.
      (4). Gasoline Fire Pumps.
      (5). Eductors.
   b. Emergency Repair Equipment.
      (1). Portable Cutting and Welding Outfits.
      (2). Portable Blowers.
      (3). Electrical Tools.
      (4). Velocity Power Tools.
      (5). Screw and Hydraulic Jacks and Chain Falls.
   c. Emergency Protection Equipment.
      (1). Oxygen Breathing Apparatus.
      (2). Hose (Air-Line) Masks.
      (3). Gas Masks.
      (4). Asbestos Suits.
      (5). Chemical Defense Protective Clothing.
      (6). Shallow-Water Diving Equipment.
   d. Detection Equipment.
      (1). Explosimeter.
      (2). Flame Safety Lamp.
      (3). Chemical, Biological, and Radiological Detectors.
   e. Fire-Fighting Equipment.
      (1). Hose and Fittings.
      (2). High-Capacity Fog-Foam System.

(3). Continuous Type Foam Generators.
(4). N. P. U. (Navy pick-up) Nozzle and Foam.
(5). Installed CO_2 Systems.
(6). Portable CO_2.
(7). Steam Smothering.
(8). Sprinkler Systems.

3. Interior Communication.
   a. Sound-Powered Phones.
   b. Secondary Communication Equipment.
      (1). 4MC.
      (2). 1MC.
      (3). Ship's Service Telephones.
   c. Primary and Secondary Sound-Powered Circuits.
   d. Emergency Communication Circuits.
   e. Priority of Circuits.
   f. Relationship of Repair Party Communication to Damage Control Central.

4. Operational Procedures.
   a. Methods of Fire Fighting.
      (1). Class A.
      (2). Class B.
      (3). Class C.
   b. Radiological, Biological, and Chemical Warfare Defense.
      (1). Gas Detection and Identification.
      (2). Monitoring and Decontamination.
      (3). Self-Aid and First Aid.
   c. Deck Machinery.
   d. Steering Machinery.
   e. Air Compressors.
   f. Applying First Aid.
   g. Shoring.
   h. Dewatering Compartments.
   i. Emergency Cutting and Welding.
   j. Applying Emergency Patches.
   k. Maintaining Stability Through Counterflooding.

To the above list there could be added a list similar to the one shown earlier in this chapter, under the section "Knowledge Necessary for Damage Control." The nonrated or new man in a damage control organization should have a basic understanding of the subject of damage control and why he must be competent in the use and operation of damage control equipment and material.

The leading petty officer in charge of a detail or a repair party is in an excellent position to know the weak and strong points of his "team," and thereby determine what types of drills or training should be conducted. This knowledge of the men will be of aid to the Damage Control Assistant in setting up a training program and various drills.

In conducting drills and training, precautions must be taken to avoid having or establishing "key men" in the organization. These men may become injured and the resulting loss will cause confusion. If a man or petty officer is an outstanding leader of a hose party, simulate his injury and let the next man take over. Men should be rotated in their duties. As far as practical, a man should be versatile and a jack-of-all-trades; and the organization should be kept flexible.

One of the qualities of good leadership is to be able to instill interest and competition among the men in damage control drills and activities. This may not prove as easy as it sounds, because during drills one does not have the actual holes and flooding or fires burning on board ship. To simulate fires, damage, and flooding is one of the most difficult aspects of damage control training and should be given a great deal of thought. Smoke candles and red pieces of canvas can be used to represent fires and chalk marks; blue pieces of canvas or training mock-ups can be used to imitate flooding and holes in the ship; red rags and shipping tags can serve to indicate personnel injuries; shorting-out plugs can be placed in damage control telephone circuits; large tags or training mock-ups can be used to simulate breaks or holes in piping; and posters of various types can give information on damage.

A logical sequence should be followed in training men in a certain drill or subject. First, a lecture should be made to give men the purpose and importance of the drill. They must have a clear understanding as to what it is all about. Have the men walk through the drill, in order to check for proper procedure; later, speed can gradually be developed. Do not sacrifice quality for speed. Remember that speed in doing a drill comes last. Unless this training procedure is followed, confusion will result and some men may never learn the drill.

Ordinarily, all the fundamental drills should be properly held and completed before a complicated battle problem is attempted. The purpose of the battle problem is to train the damage control organization as a whole unit and to locate weak points. It is similar to the final examination after a course of study has been completed.

Do not forget the telephone talker. There are important communication drills and training that must be completed before he is ready for a battle problem, otherwise the whole top level of the damage control organization will break down. Remember that a complete prearranged battle problem can be simulated by the communication personnel under the supervision of one officer or petty officer at each station. This training of the telephone talkers can take place independently of any drill for the damage control organization as a whole unit.

QUIZ

1. What are the three basic phases of shipboard damage control?
2. Why must damage control be considered an offensive, as well as a defensive, function?
3. Where can you find detailed information concerning publications on damage control?
4. What kind of ships are issued damage control books by BuShips?
5. What are the reasons for subdividing repair parties into patrols, units, or secondary groups?
6. What is the battle station of the damage control officer?
7. What is the primary function of damage control central?

8. What source of information is available on board ship to help you locate any section of the ship or of the ship's systems?
9. What three factors determine the number and the ratings of men assigned to a repair party or repair station?
10. Under battle conditions, what personnel will be immediately available for fighting fires?
11. What type of power is needed to operate battle telephone systems?
12. Which sound-powered circuit is common to the damage control central station and all repair parties?
13. What circuit is installed on some ships to provide emergency communication between the open bridge, main engine control, damage control, and the steering gear room?
14. Why is it not possible to rely on ship's service telephones for damage control communications?
15. Why is it not desirable to use the 1MC system for damage control communications?
16. Why must each repair station keep a written log of all information and orders given by damage control central, even if they do not apply to the specific station?
17. What is the purpose of action cut-out switches for battle telephone systems?
18. Is it good practice to establish "key men" in the damage control organization?
19. In training men for damage control, should speed or skill be most emphasized at the beginning?
20. What is the purpose of a battle problem?

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

A BIGGER JOB

1. In the qualifications for advancement in rating to MR1 and MRC.
2. What is to be done; when it is to be done; how to accomplish it; and why it must be done.
3. To catch mistakes before they cause excessive loss of time, labor, and material.
4. Visual aids, such as charts, diagrams, working models, sound movies, and slides.
5. Navy Department; Shore Establishment; and Operating Forces.
6. Chief of Naval Operations.
7. BuPers.
8. BuShips.
9. A force that has been organized to accomplish a special task.
10. The name given to an occupation which requires, basically, related aptitude, training, experience, knowledge, and skills.
11. Naval Reserves.
12. Your specialty and any other Navy skills you may know.

CHAPTER 2

ORGANIZATION AND REPAIR PROCEDURES

1. A repair ship is mostly concerned with maintenance; a tender supports the assigned ships in every way.
2. A repair ship supports various types of ships; a tender supports one specific type.

3. AR.
4. ARS.
5. AD.
6. The repair of Diesel engines.
7. ARB.
8. A squadron of 12 submarines.
9. The maintenance of an efficient and well-organized repair department.
10. The assistant repair officer.
11. The diving and salvage officer.
12. The shop supervisor.
13. The ship superintendent.
14. Repairs.
15. Alterations affecting the military characteristics of the ship.
16. The number of the alteration within a type; the number of the alteration for a specific ship within the type; and the appropriate expenditure account chargeable.
17. Alterations equivalent to repairs.
18. A restricted availability.
19. For the accomplishment of specific items of work to be done with the ship not present.
20. Representatives of the ship, the repair department, and the type commander.
21. Steam and electricity.
22. A job order.
23. The shop supervisor.
24. (1) Standard stock; (2) BuShips special material; (3) BuShips repair parts.
25. Standard stock.
26. BuShips special material is usually permanent or nonconsumable equipment; BuShips repair parts are parts, fittings, or accessories for BuShips special material.
27. (1) The ship's allowance list; (2) name plates on equipment; (3) catalogs and instruction books issued by the manufacturer; (4) the ship's Machinery Index; (5) ships' plans; (6) the supply officer's Stock Cards.

28. Priority 3.

29. Allotments granted by BuShips.

CHAPTER 3

TURRET LATHES AND BORING MILLS

1. They are basically alike, but their tooling is different.
2. Feed trips and positive stops on the cross slide unit.
3. It transmits power from the spindle of the machine to the cross slide and hexagonal turret.
4. Carbon tool steel, high-speed steel, Stellite, carbides, and diamonds.
5. Because the angles do not change as the cutter is reground, and proper clearances and rakes are more easily maintained.
6. By getting the best combination of back and side rake angles, in combination with speeds and feeds.
7. By preventing overheating of the work, with consequent change in size.
8. If the rollers are behind the cutter they burnish the workpiece and thus may eliminate the need for polishing or grinding.
9. Light pressure should prevent them from turning when the bar stock is revolved.
10. The faces of the two rolls must be in line; the leading corners of the rolls must be perfectly round and exactly equal; and the end play in the rolls should not exceed 0.003 in.
11. To bore holes too small to be cut with a boring bar and inserted cutter.
12. Sleeves.
13. In the hexagon turret.
14. About 2½ times the length of the workpiece.
15. The size of the hole being bored—the smaller the hole, the greater the front clearance angle required.
16. Circular forming cutters.
17. On a toolroom grinder where they can be rigidly supported and ground to maintain the original relief angles.
18. Because it is not necessary to reverse the spindle to withdraw the tap.
19. Soluble oil.

20. With forming cutters, roller rest taper cutters, or taper attachments.
21. The roller rest taper turners.
22. The pushout, the drawback, and the stationary.
23. The expanding plug-type arbor.
24. Machining large circular castings.
25. The cross slide.
26. In the lower end of a ram.
27. By power-driving the platen in a direction transverse to the bed of the machine.
28. Any size up to and including 4 in. in diameter.

CHAPTER 4

GEARS AND GEAR CUTTING

1. The milling machine.
2. Spur gears, bevel gears, helical gears, and worm gears.
3. It is the distance in inches from the center of one tooth to the center of the next tooth, measured along the arc of the pitch line.
4. It is the distance in inches from the center of one tooth to the center of the next tooth, measured along the straight line (chord) which subtends the arc of the pitch line.
5. Pitch circle.
6. Because the diametral pitch system simplifies the gear calculations and measurements.
7. Pressure angle.
8. Standard involute, with pressure angle of 14½°.
9. Make a trial cut by nicking the blank all the way around its circumference. If the cutter does not line up with the first nick, an error has been made in setting the dividing head.
10. The circular pitch.
11. Planing with a formed tool.
12. Greater strength.
13. Miter gears.
14. It equals the back cone radius times 2 times the diametral pitch.
15. Thickness of tooth.

16. Worm gearing.
17. First the teeth are formed roughly by milling gashes around the worm-gear blank; then the teeth are hobbed.
18. The design of the gears and the relative position of the shafts.
19. The function of the gear.
20. Cooling and lubrication.
21. Backlash.

CHAPTER 5

GRINDING WORK

1. Cutter grinders.
2. Common-center and centerless.
3. The selection of the proper grinding wheel.
4. Aluminum oxide and silicon carbide.
5. Hard but brittle wheels.
6. One produced by a combination of several sizes of abrasives.
7. To the spacing between the abrasive particles in the wheel.
8. Vitrified clay.
9. Rubber.
10. Abrasive, grain, grade, structure, and bonding material.
11. Fine.
12. No.
13. Cleaning out imbedded stock and removing grains that have become rounded through use.
14. It dissipates the heat that might cause distortion of the material; it prevents pitting or scoring of the wheel; and it settles the dust caused by the grinding operation.
15. Between the collet and the ring, with washers on both sides of the wheel, and with the transfer marks on collet and ring properly lined up.
16. To help maintain balance of the collet and ring assembly.
17. Checking the diamond for sharpness and tightness in the nib.
18. Vertically, so that the diamond will true the face of the grinding wheel.

19. As many as the chuck will hold, PROVIDED that a retaining ring is used, or that each piece overlaps part of two poles of opposite polarity.
20. By disengaging the latch and allowing the lever to return to its OFF position.
21. By turning the switch handle to RELEASE, and then immediately to OFF.
22. It should be not more than one-half of the wheel width.
23. The throttle lever.
24. From zero to 20 fpm.
25. They can be used by the operator to accurately obtain the same roughing, finishing, and truing speeds for any part ground.
26. The setting of the feed box adjustments.
27. To correct the automatic feed so that it will allow for wheel wear that takes place during grinding.
28. Zero.
29. Only one piece can be ground at a time; the work must be exactly centered, by use of a pilot or a locating ring.
30. By the hand screw clamp, and with the rear control traverse knob pushed in.
31. $\frac{1}{10}$ in.
32. The drive is from a 2-step pulley on the motor shaft, through an endless belt, to a single-step pulley on the wheel spindle.
33. A special pulley should be used, and the belt is placed on the small step.
34. Between 5,000 and 6,500 fpm.
35. $$\text{Rpm spindle} = \frac{\text{rpm motor times diameter of pulley on motor}}{\text{diameter of pulley on wheelhead}}$$
Surface speed of wheel (ft/min) = rpm spindle times $\dfrac{\text{3.14 diameter of wheel}}{12}$
36. Up to 2 inches per foot of stock.
37. This shifts the position of the T-slot and changes the center of gravity of the attachment and cutter, so that there is no danger of the set-up tipping toward the wheelhead.
38. To absorb the shock of impact at the end of the stroke.
39. The centering gage.
40. To help in setting the column to zero—that is, with tailstock centers and the center of the grinding wheel at the same height from the table.
41. Toward the cutting edge of the tooth.

42. By turning the spindle end for end.
43. It breaks down more easily than a hard wheel, and is therefore less liable to burn the cutter.
44. To allow some of the generated heat to dissipate.
45. Dry.
46. The clearance setting dial at one end of the spindle housing; the clearance and set-up graduations for the vertical swivel bearing; and the clearance and set-up graduations for the horizontal swivel bearing.
47. The plain cylindrical grinder.
48. Universal cylindrical grinder.
49. The taper scales on the upper table read ½ of the whole taper angle.
50. The cuts should be light, the work speed should be kept slow, and a large amount of coolant should be used.
51. The grinding wheel, the regulating wheel, and the workrest.
52. The relative positions of the regulating wheel axis and the grinding wheel axis, and the speed of the regulating wheel.
53. Cylinder can be fed completely through the machine. Work must be ground to a shoulder.
54. 12-in. diameter saws.
55. Because the ends or face of the teeth, and the corners also, must be sharpened.
56. On an arbor set in a taper shank mill bushing.
57. It ensures rapid and precise indexing.
58. The cutting clearance on the sides of the teeth can be reduced to a very small angle.
59. To prevent regrinding of the secondary clearance each time that the primary clearance is ground.
60. In storage racks, and in a dry place.

CHAPTER 6

METAL FINISHING PROCEDURES

1. Case-hardening changes the chemical composition of the surface metal; other heat-treating processes involve no change in the composition of the metal.
2. Case-hardening.
3. Normalizing, annealing, hardening, and tempering.
4. To increase hardness or toughness; to control the size and shape of articles during hardening; or to increase red-hardness.

5. Hardness.
6. Carburizing, cyaniding, and nitriding.
7. It does not necessarily increase hardness, but it does cause deeper hardness penetration.
8. High-speed steel.
9. About 1,600° F.
10. The length of time that the piece is held at the proper temperature in contact with the element being added.
11. About 0.080 in.
12. The ease with which a case can be produced.
13. Nitriding.
14. Sharp corners, and excessive difference in the thicknesses of various parts of the tool.
15. Overheating prevents proper tinning and bonding, and may damage both the base metal and the filler metal.
16. Iron-base alloys, in rod form; tungsten or cobalt alloys, in rod form; and tungsten carbide, in the form of small cast inserts.
17. Because the heat required for application will damage the base metal.
18. Oil quenching.
19. By grinding.
20. The oxyacetylene torch.
21. (1) Preparation of the surface, (2) application of the metallic coating by spraying, (3) final finishing of the sprayed surface.
22. Almost any metal or alloy which can be made in rod or wire form.
23. It is an oxyacetylene torch with a compressed air motor to feed the wire through the gun to the melting point of the flame.
24. The application of too heavy coatings of the sprayed metal.
25. By wet grinding.
26. A wheel of relatively coarse grain and low bond strength.

CHAPTER 7

MAIN STEAM PROPULSION PLANTS

1. In the turbines.
2. The split-plant arrangement.
3. (1) Minimum size and weight; (2) maximum flexibility; (3) reliability; (4) maximum efficiency; (5) maximum accessibility.

4. 2 hours.
5. First cut in two burners on the saturated side, then one on the superheater side, until the load requirement has been met.
6. Drop the superheat off the boilers to 600° F. at the rate of about 50° F. every 5 minutes; shift the load to the boilers on the saturated side; secure the superheater fires.
7. Attempt to localize the damage.
8. Lack of proper attention.
9. (1) Shut off oil supply to burners; (2) close feed-check valves; (3) close boiler steam stop valves.
10. All available steam.
11. Close the boiler steam stop; at the same time, gradually open the safety valves.
12. Make sure that all parts of the turbine are evenly heated.
13. Before the turbine rotors are turned over.
14. Condensate is more easily discharged through the astern turbines.
15. Water or other foreign matter in the turbine.
16. To keep the bearing metal from freezing to the shaft.
17. Because turbines operate most efficiently at high speeds, while propellers operate most efficiently at relatively low speeds.
18. When the thrust shifts from the bottom half to the top half of the reduction gear bearings.
19. (1) To maintain a vacuum; (2) to recover feed water.
20. Because that is where the lowest absolute pressure is maintained.
21. (1) Dial-type vacuum gage; (2) absolute pressure gage; (3) measurement of the temperature of steam entering the condenser.
22. To keep a sufficient amount of condensate in the hot well.
23. Loss of vacuum.
24. Every 15 minutes while under way, and every 30 minutes while standing by.
25. (1) Maintenance of a sufficient flow of cooling water; (2) maintenance of proper drainage.
26. In the deaerating feed tank.
27. By recirculating condensate from the air ejector discharge line back to the main condenser hot well.
28. The water must be heated and deaerated.
29. The make-up and excess-feed valves.
30. It might cause damage to the main feed pump by reducing the suction pressure below the designated limit.

31. By the use of feed booster pumps.
32. The superheat temperature of the line must be lowered slowly until it is almost the same as the steam temperature of the incoming boilers.
33. To provide maximum protection to the superheater.
34. The chain-driven pumps.
35. (1) The temperature of the circulating water; (2) the quantity of heat to be removed from the oil; (3) the cleanliness of the oil cooler.
36. Continuous purification.
37. Because the thermometers may indicate only the average oil temperature within the bearing reservoir.
38. At least 12 hours of intermittent operation during each 24-hour period.
39. Chain oilers are more easily removed and replaced; ring oilers are more durable.

CHAPTER 8

REFRIGERATION

1. The low-pressure side.
2. Freon–12.
3. Air.
4. Diaphragm or ring plate types.
5. Crankshaft seals.
6. Multiple V-belt drive, or drive with coupling.
7. By stopping the system when the desired degree of coolness has been reached in all spaces.
8. The relief valve.
9. In the liquid receiver.
10. Between the receiver and the evaporator; also after the receiver.
11. The "king" solenoid valve.
12. Silver-soldering or brazing.
13. To permit operation of the spare refrigerating machine on the load.
14. At least once a week.
15. Every two hours.
16. From ½ to ¾ up in the sight glass.
17. Navy contract oil, symbol 2135.

18. Because the compressor crankcase is under a slight pressure. All the oil would blow out, and you couldn't get the plug back in to save proper oil level.
19. Belt dressing should never be used.
20. At least once a month.
21. At least once every two weeks.
22. Sterile mineral oil.
23. $\frac{3}{16}$ in.
24. "Hot gas" defrosting lines.
25. The halide torch.
26. The detailed instructions which apply to the particular refrigeration plant being serviced.

CHAPTER 9

AIR CONDITIONING

1. To keep personnel comfortable, alert, and physically fit at general quarters battle stations.
2. Saturated air.
3. The rise in temperature makes it possible for the air to hold more moisture.
4. The weight in grains of water vapor per pound of dry air.
5. Relative humidity.
6. Relative humidity.
7. When the air is saturated.
8. The air motion causes sensory stimulation of the skin, and it removes both heat and moisture from immediate proximity to the body.
9. By radiation, convection, and conduction; and as a by-product of internal physiological processes.
10. About 45 percent radiation, 30 percent convection and conduction, and 25 percent by evaporation.
11. Effective temperature.
12. From 30 to 70 percent.
13. A refrigerating system using mechanical compression.
14. Because of the larger pressure drop between the two ends of the cooling coils, in the air conditioning system.
15. The principle of cooling water by evaporation.

16. The lithium bromide plant.
17. Main engineering spaces.
18. At least every 4 hours, or at the discretion of the damage control officer.
19. One forward, one midships, and one aft.
20. Chilled water.

CHAPTER 10

DIESEL ENGINES

1. Operating cycle.
2. One.
3. They serve to maintain the working or moving parts in their proper position so that the gas pressure produced by combustion is used to push the piston and rotate the crankshaft.
4. Bore.
5. Some have rotary motion, some have reciprocating motion, and some have both rotary and reciprocating motion.
6. Mechanical strength and static and dynamic balance.
7. Cast-iron pistons have the same coefficient of expansion as the cylinder liner.
8. Valve gear.
9. One-half the crankshaft speed.
10. Poppet valves.
11. The provision of a clearance or lash between the top of the valve stem and the valve-lifting mechanism.
12. Common-rail, individual-pump, and distributor systems.
13. Because it is difficult to control accurately the small quantities of fuel required by these engines.
14. It is a single unit which combines a pump and a fuel-spray nozzle.
15. Pump, cooler, filter, and strainer.
16. Fresh water which has been treated to remove scale-forming impurities.
17. It helps to provide a uniform and continuous air supply to the engines.

18. Because so much of the heat of compression goes into warming the engine parts that the air temperature does not go high enough for the fuel to ignite.

19. Wet type exhaust silencers.

20. To supply air for scavenging and for supercharging the cylinders.
21. The centrifugal force of a rotating weight is balanced by a helical coil spring.

22. By adjusting the initial compression of the speeder spring.

23. Overspeed trip.

24. Electric systems and compressed air systems.

25. By means of reverse gears which reverse the direction of rotation of the propeller shaft, without changing the direction of rotation of the Diesel engine.

26. By using compressed air in conjunction with the air-starting system.

CHAPTER 11

BALANCING MACHINES AND PROCEDURES

1. If placed on a pair of knifeways, it will remain in the position in which it was placed.

2. If it is put into rotary motion, there is no vibration.

3. The distribution of mass in the rotary part is altered so as to eliminate vibration at the supporting bearings.

4. Less vibration and noise, greater operating efficiency, and longer life for bearings and for machines.

5. The parts may be sprung or bent; counterweights may be put back in the wrong place, or left out altogether; or adding or removing material may cause unbalance.

6. Bent blading erosion.

7. No.

8. No.

9. The axis of the flywheel is not in alignment with the axis of the crankshaft.

10. Ounce-inches (the product of weight and displacement).

11. 5,000 lb.

12. Static balancing.

13. Opposite the heavy point, and at a distance of 1.5 inches from the rotational axis.

14. No.

15. No, because the centrifugal forces which these weights produce when the cylinder is rotating will make the ends of the cylinder tend to move in opposite directions.

16. In each of two planes, which must be spaced some distance apart, and both of which must be perpendicular to the rotational axis.

17. Locating and measuring the required corrections, and applying the corrections.

18. The design and the function of the unbalanced part.

19. Yes.

20. At both.

21. No.

22. By the amount of motion between the cradle and the machine base, at a point away from the fulcrum.

23. The mass of the cradle itself acts to reduce the vibration caused by a given unbalance, and to this extent reduces the accuracy of the unbalance measurement.

24. A point on the nodal bar and at which an unbalance indicator will show unbalance in one plane only.

25. The small motion involved makes it difficult to locate the nodal point accurately, and the mass of the nodal bar itself reduces the accuracy of measurement.

26. As the bearings vibrate, the coils vibrate in the magnetic fields, and generate an alternating voltage.

27. By means of a voltage divider and a left-right switch.

28. Negligibly decreased.

29. Mechanical, optical, and electrical.

30. Because of the inertia of their members.

31. The unbalance that produces a centrifugal force just sufficient to overcome the friction in the pin joints of the levers.

32. Optical lever.

33. Each time the voltage generated by vibration changes from negative to positive, the stroboscopic lamp is triggered.

34. The location.

35. Greater.

36. The location.

37. When the base of the vibrometer is held against the structure, the only reed that will vibrate with a pronounced amplitude will be the reed that has a natural frequency corresponding to the vibration rate of the structure.

38. The balancing machine is receiving vibrations, transmitted through floor or bench, from adjacent machinery which vibrates at a rate corresponding to that of the work supports.

39. Machines that rotate the workpiece at a rate which corresponds to the natural frequency of the work-supporting structure.

40. A reduction.

41. Variation in the speed at which the workpiece is rotated, and vibrations transmitted, from other machinery, to the work-support and the piece.

42. It filters out all frequencies other than the rotational frequency of the workpiece.

43. Belt drive.

44. No, it is a conversion factor.

45. Wire solder (of measured length and given diameter) ; strip metal (of measured length and given cross section) ; washers or slugs (of known weight).

46. Milling, grinding, shaping, and drilling.

47. Portable balancing equipment.

CHAPTER 12

RUNNING A MACHINE SHOP

1. It speeds up production, and it tends to result in better care and cleanliness of the tools.

2. Daily.

3. Because it is definitely related to the efficiency and safety of shop operation.

4. Series 12000 (title B).

5. In the BuShips Allowance Book for the ship.

6. A warning card should be attached to the switch, to make sure that the power is not turned on by other persons.

7. The instruction book furnished by the manufacturer of that machinery.

8. In the *Navy Filing Manual.*

9. The subject-matter group designation (which follows the class-of-ship designation) is an "S" followed by numbers—for example, S4700 refers to the subject-matter of pumps.

10. Routine.

11. In general, you should select a metal of higher specification, if substitution is necessary.

12. Experience in doing repair work is the only way to learn how to make accurate estimates of time.

13. The other shops should make time estimates for their own part of the work. The chief in charge of the machine shop should NOT attempt to make estimates for the other shops.

14. When planning the procedure, before the work is actually begun.

15. Because the repair job itself may cause the unit to become unbalanced.

16. In order to give the inexperienced men some training and experience.

17. The chief in charge of the machine shop.

18. Supervisory and managerial duties.

19. "Man-hours" is not a measure of time. It is a measure of amount of work.

20. The man-hours, the material used, and a full description of the work accomplished.

CHAPTER 13

DAMAGE CONTROL ORGANIZATION

1. (1) Preliminary precautions; (2) minimizing and localizing damage; (3) emergency repairs or restorations.

2. Because the ability of a ship to accomplish an assigned mission may depend upon the effectiveness of damage control measures.

3. From the ship's damage control officer, or from chapter 88 of the BuShips *Manual.*

4. Ships which were originally constructed as naval vessels.

5. To disperse personnel, and to obtain a wide coverage of the assigned areas.
6. The damage control central station.
7. To collect and compare reports from the various repair parties in order to determine the condition of the ship and the action that should be taken.
8. Diagrams which are kept at damage control central and at repair party stations.
9. (1) The location of the station; (2) the portion of the ship assigned to that party; (3) the total number of men available for all stations.
10. Only the members of repair parties.
11. Battle telephone systems are sound-powered circuits, requiring no outside source of power.
12. 2JZ.
13. X40J.
14. They are not part of the battle system, and may go out of commission early in action.
15. Too many stations other than damage control are affected.
16. Because any station may succeed to control, and in that event will need to know what casualties are being handled by all other stations.
17. To isolate damaged or short-circuited portions of a circuit, thus restoring the remainder of the circuit to use.
18. Definitely not, since the loss of "key men" could cause great confusion.
19. Skill.
20. To train the damage control organization as a whole unit, and to locate weak points.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

MACHINERY REPAIRMEN (MR)

RATING CODE NO. 3900

General Service Rating

Machinery repairmen make all types of shop repairs on shipboard machinery. This requires skillful use of lathes, milling machines, boring mills, grinders, power hacksaws, drill presses, and other machine tools, as well as all hand tools and measuring instruments in a machine shop.

Emergency Service Rating

Same as General Service Rating.

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see Manual of Enlisted Navy Job Classifications, NavPers 15105 (Revised), codes MR–4400 to MR–4499.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	Applicable Rates
	MR
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Locate principal isolation valves of fire main system	3
2. Identify stock metals by standard markings	3
3. Read mechanical shop drawings	3

Qualifications for Advancement in Rating	Applicable Rates MR
4. Insert metal band saws and files of various widths into the appropriate machine, and make proper adjustments	3
5. Use metal band saw attachments in contour sawing	3
6. Perform angular metal band saw cutting	3
7. Perform plain milling on round, square, and flat shapes of metals and plastics on a milling machine	3
8. Mill keyways in shafts on a milling machine	3
9. Machine flats on nuts and bolts on a milling machine	3
10. Compute feeds and speeds for milling machines	3
11. Engrave brass, Monel, and plastic name plates with pantograph	3
12. Set up and use index plates and radius plates on circular work on a pantograph	3
13. Grind pantograph cutter bits and stylus points, using pantograph bit grinder	3
14. Compute feeds and speeds for shapers and planers	3
15. Machine flat surfaces, using a shaper or planer	3
16. Lay out and machine a V block, using a shaper or planer	3
17. Machine all surfaces of a rectangular block, using a shaper or planer	3
18. Grind cutter bits for the following operations, using a bench grinder: Left-hand turning, round-nose turning, right-hand turning, left-hand facing, threading, and cutting-off	3
19. Grind chisels, screwdrivers, center punches, and twist drills on a bench grinder	3
20. True and dress grinding wheels on a bench grinder	3
21. Grind tungsten carbide tools	3
22. Perform plain turning between centers on an engine lathe	3
23. Using a three-jaw chuck, perform drilling, reaming, tapping, and boring operations on an engine lathe	3
24. Cut external American National screw threads, using an engine lathe	3
25. Use compound rest in taper turning on an engine lathe	3

Qualifications for Advancement in Rating	Applicable Rates MR
26. Compute feeds and speeds for plain turning on an engine lathe	3
27. Adjust feeds and speeds for drilling and reaming on a drill press	3
28. Perform drilling, reaming, tapping, counterboring, and countersinking, using a drill press	3
29. Lay out and drill round stock, using drill press with V blocks	3
30. Cut external and internal Acme and square threads using an engine lathe	2
31. Mount work off-center on an engine lathe faceplate for eccentric machining operations	2
32. Turn replacement pump shafts and valve stems, using an engine lathe	2
33. Use steady rest and follower rests in turning long shafting on an engine lathe	2
34. Cut tapers, using tailstock set-over method or taper attachment on an engine lathe	2
35. Grind in and set cutters for a horizontal turret lathe	2
36. Set up for taper turning on a vertical turret lathe	2
37. Turn out replacement parts in accordance with drawings and specifications	2
38. Lay out pipe and valve flanges, using temporary centers	2
39. Set up various cutter combinations on arbor of a milling machine	2
40. Cut T-slots and dovetails, using a milling machine	2
41. Lay out and cut keyways in gear blanks, using a shaper or planer	2
42. Cut keyways in shaft with a shaper or planer	2
43. Machine a concave or convex surface, using a shaper or planer	2
44. Grind cutter bits on a surface grinder for Acme and square threading	2
45. Machine steel wedges, using universal table and vise on a shaper or planer	2
46. Cut a gear rack, using a shaper or planer	2
47. Mount, dress, and true grinding machine wheels	2

Qualifications for Advancement in Rating	Applicable Rates MR
48. Grind spacers and shims, using a magnetic chuck on a surface grinder	2
49. Grind valve seats and disks, using a lathe with grinding machine attachments	2
50. Operate a metal hardness tester and interpret its readings	1
51. Make working sketches of machine parts	1
52. Set up dividing head of milling machine for rapid and plain indexing	1
53. Perform drilling, reaming, and boring operations, using a boring mill	1
54. Aline and bore split bearings, using a boring mill	1
55. Face valve flanges, using a boring mill and a facing head	1
56. Aline and bore pump cylinder liners, using a boring mill	1
57. Use portable balancing equipment in checking the balance of machinery	1
58. Operate balancing machines, making all necessary corrections	1
59. Prepare surfaces for metal spraying	1
60. Set up and operate metalizing equipment for spraying	1
61. Set up and grind slabbing cutters, formed cutters, angular cutters, and end mills, using a grinding machine	1
62. Set up and grind pump shafts, using a cylindrical grinder	1
63. Select grinding wheels and cutting fluids	1
64. Broach internal spline in gear blank, using a slotter or keyseater	1
65. Set up and machine spur gears and worm gears, using a milling machine	1
66. Set up and perform spiral milling on a milling machine	1
67. Use circular milling table for facing or T-slot milling on a milling machine	1
68. Cut multiple screw threads, using an engine lathe	1
69. Use relieving attachments when manufacturing taps and dies on an engine lathe	1

Qualifications for Advancement in Rating	Applicable Rates MR
70. Set up a horizontal turret lathe for manufacture of stud bolts	1
71. Machine piston rings and pump liners, using a vertical turret lathe	1
72. Make all required shop inspections and tests on repaired machinery and equipment	C
102 MAINTENANCE AND/OR REPAIR	
1. Lubricate all machine tools in shop	3
2. Use test bar and dial indicator to check alinement and accuracy of engine lathes, turret lathes, and milling machines. Correct deficiencies	C
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Take charge of tool issue room	2
2. Take charge of a shipboard repair detail	2
3. Supervise the manufacture of replacement parts	1
4. Supervise shop repair and overhaul of machinery and equipment	1
5. Enforce personnel and material safety precautions in all shop work	1
6. Estimate time and material needed for machine shop work	C
7. Schedule and assign work load to machines	C
8. Locate and use appropriate sections of BuShips Manual, manufacturers' instruction books, and handbooks to obtain data when repairing machinery	C
9. Assign personnel to shop machines	C
10. Enforce proper working procedures on machine tools	C
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Safety precautions involved in performing tasks appropriate to applicable rates listed under 100 Practical Factors.	
2. Physical properties of base metals, alloys, and plastics, and effect of these properties on cutting speeds and choice of cutting tools	2
3. Advantages and limitations of high-speed steel and cemented carbide tools	2
4. Factors to be considered in selection of grinding wheels and cutting fluids	1

Qualifications for Advancement in Rating	Applicable Rates MR
5. Know standard metal hardness tests and equipment used	1
6. Procedures for laying out spur gears	1
7. Heat treatments required to change properties of ferrous and nonferrous metals	C
202 MAINTENANCE AND/OR REPAIR	
1. Care and stowage of the following precision instruments: Micrometers, depth gages, vernier calipers, protractors, and dial indicators	3
2. Use of test bar and dial indicator to check alinement and accuracy of engine lathe, turret lathe, and milling machine	C
3. Selection and use of proper cutting oils and lubricating oils	C
203 ADMINISTRATIVE AND/OR CLERICAL	
1. Use of allowance lists for machine shop spare parts, tools, and supplies	1
2. Records kept by the repair departments: Work requests, job orders, progress reports, and departure reports	C
3. Procedures for obtaining replacement parts and supplies	C
4. Inventory of machine tools, accessories, portable power tools, and hand tools	C

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